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A volume of two reports dealing with investigations relating to the composition and to the methods of control of air pollutants emitted from the exhausts of motor vehicles~~, is presented~~. A report on neutralizing automobile exhaust gases presents the following information: Composition and toxicity of exhaust gases; control of exhaust gases; methods of reducing the formation of toxic components in exhaust gases; Neutralization of toxic components of exhaust gases; and prospective automobile engines and extent of possible poisoning of the atmosphere by them. The second report discusses the determination of the composition of exhaust gases for carburetor engines under different operating conditions.

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Automobiles
Exhaust gases
Toxicity
Composition
Atmosphere contamination control
Chemical analysis
Afterburners
Carburetors

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Air pollution control
Engine operation modification

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AICE* SURVEY OF USSR AIR POLLUTION LITERATURE

Volume X

THE TOXIC COMPONENTS OF AUTOMOBILE EXHAUST GASES: THEIR COMPOSITION UNDER DIFFERENT OPERATING CONDITIONS, AND METHODS OF REDUCING THEIR EMISSION

Edited By

M. Y. Nuttonson

The material presented here is part of a survey of
USSR literature on air pollution
conducted by the Air Pollution Section
AMERICAN INSTITUTE OF CROP ECOLOGY

This survey is being conducted under GRANT 1 RO1 AP00786 – APC
OFFICE OF AIR PROGRAMS
of the
U.S. ENVIRONMENTAL PROTECTION AGENCY

*AMERICAN INSTITUTE OF CROP ECOLOGY
809 DALE DRIVE
SILVER SPRING, MARYLAND 20910

1971

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PREFACE

The present volume consists of reports dealing with a number of investigations relating to the composition and to the methods of control of air pollutants emitted from the exhausts of motor vehicles.

Contamination of the natural environment constitutes a major problem in all industrial regions and in the urban areas of the Soviet Union. The rapid development of various industrial enterprises throughout much of the country and the extensive use of the internal-combustion engine for motor vehicle transportation contribute greatly to massive qualitative changes in man's habitat through an ever increasing pollution of air, soil, and streams. The increase in the concentration of the biologically toxic types of air contaminants impairs the well-being of humans and animals, causes injury and even death to susceptible plant species, and brings about deterioration of various materials.

The exhaust emissions of the internal-combustion engine, powered by gasoline or diesel oil, is a dominant source of aerial contamination. The majority of the current models of automobiles, trucks, and busses used extensively throughout the country contribute to a severe air-pollution problem, especially in the large cities. The principal exhaust-emitted toxic gases are carbon monoxide, unburned hydrocarbons, and nitric oxides. Also of considerable importance is the exhaust-emitted particulate matter, of which the most significant and most toxic contaminants are the lead compounds.

The levels of emission of carbon monoxide, as well as of unburned hydrocarbons and of nitric oxide, are associated with the speed of operation of the motor vehicle —— the levels of the first two being higher at idling or at low speed and decreasing with acceleration whereas the emission levels of nitric oxide increase at heavy acceleration and high speeds. The carburetion, the mechanical and electrical conditions of the engine, the nature of fuel used, as well as the conditions of motor vehicle operation in reference to load and speed, are major factors determining the nature and volume of the exhaust-emitted contaminants whose relative toxicity and adverse effects on a living organism vary considerably under diverse environmental conditions. The pollution-emission toxicity potential of automotive exhaust gases is, to a large extent, dependent upon such environmental conditions as the degree of solar irradiation, wind velocity, vertical profile of temperature, and upon the temperature inversion phenomenon.

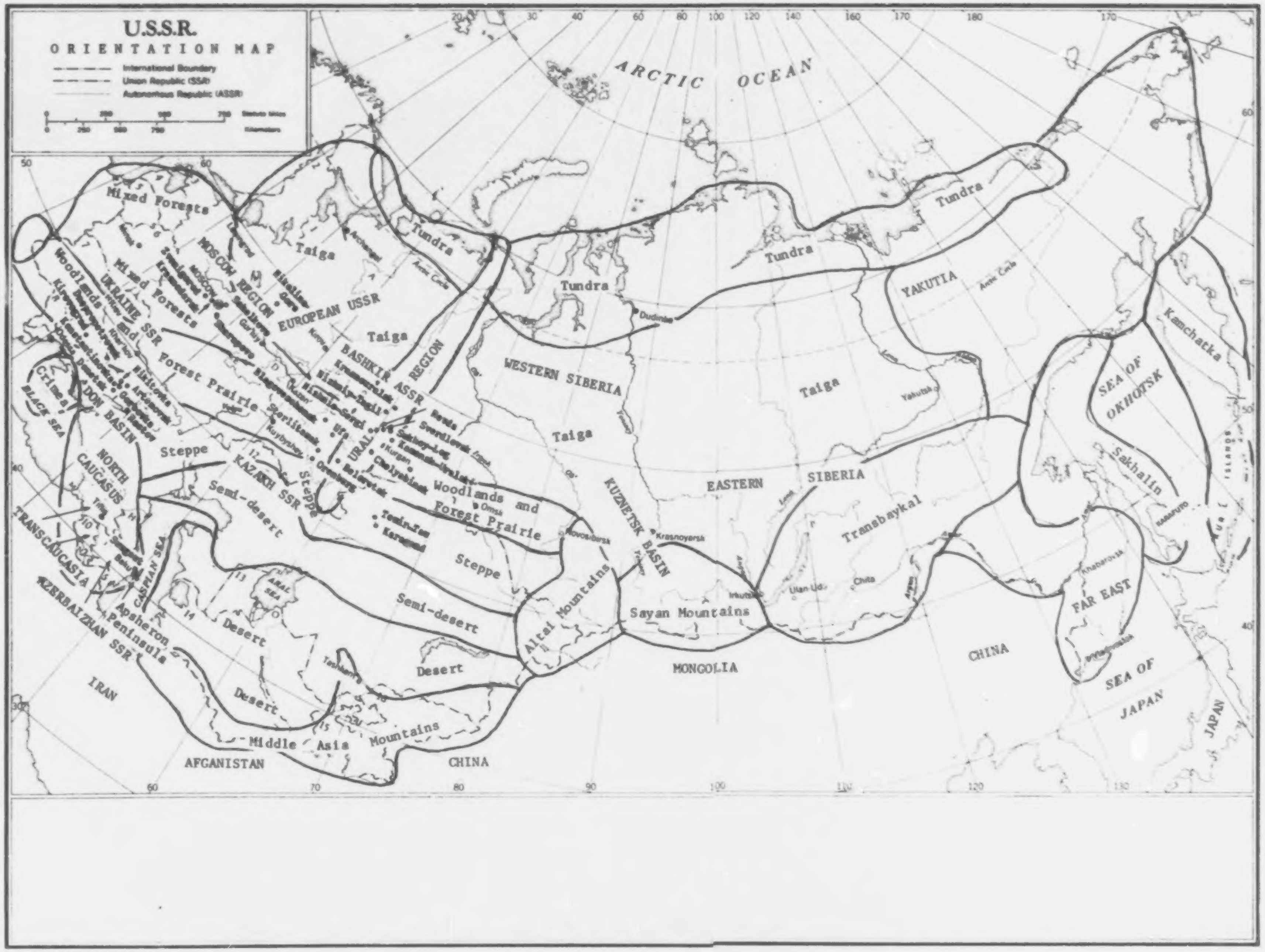
A considerable volume of basic research is conducted in the Soviet Union on methods of analysis of exhaust-emitted contaminants, on variables that affect the composition and concentration of these contaminants, and on the toxic effects of the different components of exhaust emissions. Intensive studies are being undertaken there in an effort to find suitable means to reduce the volume and toxicity level of exhaust emissions, with the ultimate goal of developing an engine with as nearly as possible a pollution-free exhaust.

Although the material brought together in this volume deals only with the problem of air pollution from the exhaust emissions of gasoline-powered automobiles, some background information on the distribution of the Soviet industry's production machine may be of interest in connection with that country's present and potential pollution problems. The planned distribution of production in the Soviet Union favors effective exploitation of the natural resources of the USSR, especially in its eastern areas where enormous natural resources are concentrated, and has led to the creation of large industrial centers and complexes of heavy industry in many of the country's economic areas (see page ix). The many diverse climatic conditions of the country and its major economic areas as well as the geographical distribution of the Soviet Union's principal industrial and mining centers and of its principal electric power stations and power systems can be seen from the various maps presented as background material in this volume.

It is hoped that the papers selected for presentation in this volume will be conducive to a better appreciation of some of the air pollution investigations conducted in the USSR. As the editor of this volume I wish to thank my co-workers in the Air Pollution Section of the Institute for their valuable assistance.

M. Y. Nuttonson

November 1971


U.S.S.R.
ORIENTATION MAP
International Boundary
Union Republic (SSR)
Autonomous Republic (ASSR)
Statute Miles
Kilometers
ARCTIC OCEAN
Mixed Forests
MOSCOW REGION
Taiga
Tundra
EUROPEAN USSR
Mixed Forests
UKRAINE SSR
Woodlands and Forest Prairie
BASHKIR ASSR
REGION
URAL
Crimea
BLACK SEA
DON BASIN
NORTH CAUCASUS
TRANSCAUCASIA
AZERBAIZHAN SSR
Apsheron Peninsula
CASPIAN SEA
Steppe
KAZAKH SSR
Semi-desert
Desert
ARAL SEA
Middle Asia Mountains
AFGANISTAN
IRAN
CHINA
WESTERN SIBERIA
Dudinka
Woodlands and Forest Prairie
Omsk
Novosibirsk
Krasnoyarsk
KUZNETSK BASIN
Altai Mountains
Sayan Mountains
MONGOLIA
EASTERN SIBERIA
Irkutsk
Ulan-Ude
Chita
Transbaykal
YAKUTIA
Yakutsk
Arctic Circle
SEA OF OKHOTSK
Kamchatka
Sakhalin
Khabarovsk
Vladivostok
FAR EAST
SEA OF JAPAN
JAPAN
KURIL ISLANDS

ADMINISTRATIVE DIVISIONS

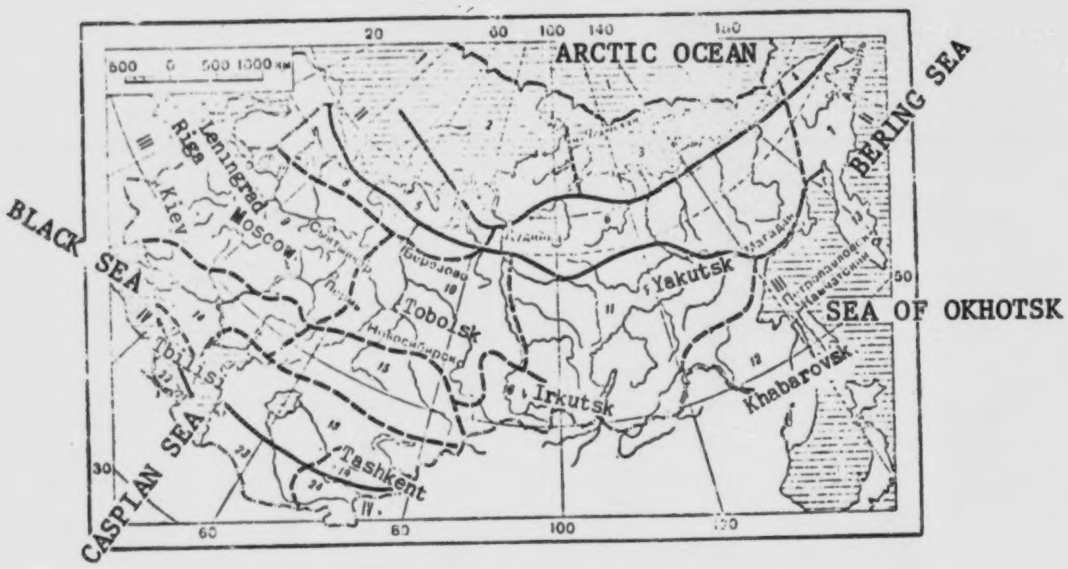
S.S.R.

1. R.S.F.S.R.
2. Karelo-Finnish S.S.R.
3. Estonian S.S.R.
4. Latvian S.S.R.
5. Lithuanian S.S.R.
6. White Russian S.S.R.
7. Ukrainian S.S.R.
8. Moldavian S.S.R.
9. Georgian S.S.R.
10. Armenian S.S.R.
11. Azerbaydzhan S.S.R.
12. Kazakh S.S.R.
13. Uzbek S.S.R.
14. Turkmen S.S.R.
15. Tadzhik S.S.R.
16. Kirgiz S.S.R.

A.S.S.R.

A. Komi ASSR
B. Udmurtskaya ASSR
C. Mariyskaya ASSR
D. Chuvashskaya ASSR
E. Mordovskaya ASSR
F. Tatarskaya ASSR
G. Bashkirskaya ASSR
H. Dagestanskaya ASSR
J. Severo-Osetinskaya ASSR
K. Kabardinskaya ASSR
L. Abkhazskaya ASSR
M. Adzharskaya ASSR
N. Nakhichevanskaya ASSR
O. Kara-Kalpakskaya ASSR
P. Buryat-Mongol'skaya ASSR
Q. Yakutskaya ASSR

CLIMATIC ZONES AND REGIONS* OF THE USSR


ARCTIC OCEAN
BERING SEA
BLACK SEA
SEA OF OKHOTSK
CASPIAN SEA
Leningrad
Riga
Kiev
Moscow
Tobolsk
Yakutsk
Tbilisi
Irkutsk
Khabarovsk
Tashkent
20
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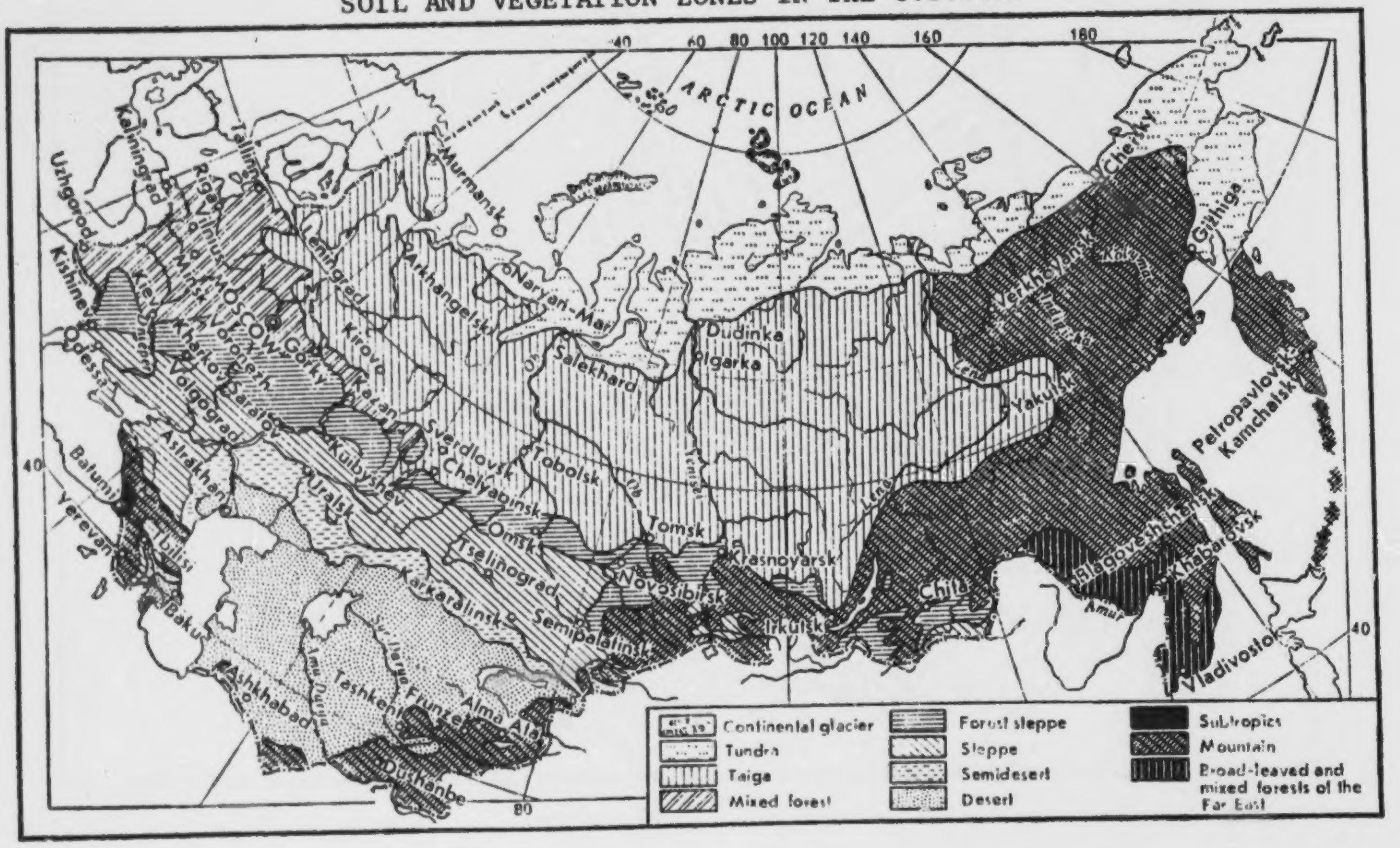
100
140
180
50
30
60
80
100
120
500 0 500 1000 km

Zones: I-arctic, II-subarctic, III-temperate, IV-subtropical
Regions: 1-polar, 2-Atlantic, 3-East Siberian, 4-Pacific, 5-Atlantic, 6-Siberian, 7-Pacific, 8-Atlantic-arctic, 9-Atlantic-continental forests, 10-continental forests West Siberian, 11-continental forests East Siberian, 12-monsoon forests, 13-Pacific forests, 14-Atlantic-continental steppe, 15-continental steppe West Siberian, 16-mountainous Altay and Sayan, 17-mountainous Northern Caucasus, 18-continental desert Central Asian, 19-mountainous Tyan-Shan, 20-western Transcaucasian, 21-eastern Transcaucasian, 22-mountainous Transcaucasian highlands, 23-desert south-Turanian, 24-mountainous Pamir-Alay

(After B. P. Alisov, "Climate of The USSR", Moscow 1956)

SOIL AND VEGETATION ZONES IN THE U.S.S.R.


ARCTIC OCEAN
Murmansk
Leningrad
Arkhangelsk
Naryan-Mar
Salekhard
Dudinka
Igarka
Verkhoyansk
Yakutsk
Gizhiga
Petropavlovsk-Kamchatsk
Kaliningrad
Uzhgorod
Kishinev
Odessa
Riga
Tallinn
Vilnius
Minsk
Kiev
Moscow
Gorky
Kirov
Kharkov
Voronezh
Volgograd
Saratov
Kuibyshev
Kazan
Sverdlovsk
Chelyabinsk
Tobolsk
Omsk
Tomsk
Krasnoyarsk
Novosibirsk
Irkutsk
Chita
Blagoveshchensk
Khabarovsk
Vladivostok
Amur
Lena
Astrakhan
Uralsk
Tselinograd
Karaganda
Semipalatinsk
Alma-Ata
Frunze
Tashkent
Dushanbe
Ashkhabad
Baku
Tbilisi
Yerevan
Batumi
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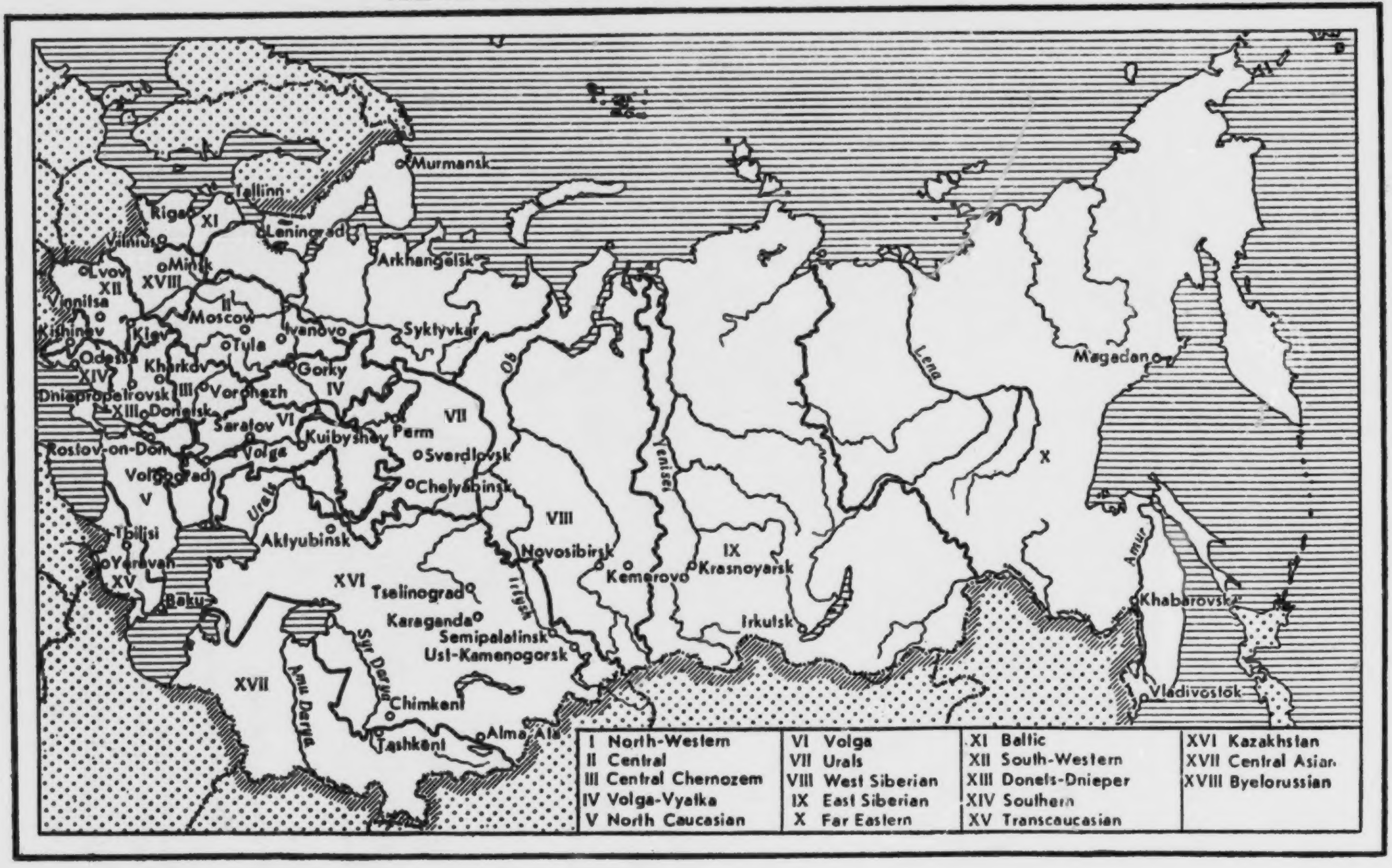
80
Continental glacier
Tundra
Taiga
Mixed forest
Forest steppe
Steppe
Semidesert
Desert
Subtropics
Mountain
Broad-leaved and mixed forests of the Far East

(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

MAJOR ECONOMIC AREAS OF THE U.S.S.R.


I North-Western
II Central
III Central Chernozem
IV Volga-Vyatka
V North Caucasian
VI Volga
VII Urals
VIII West Siberian
IX East Siberian
X Far Eastern
XI Baltic
XII South-Western
XIII Donets-Dnieper
XIV Southern
XV Transcaucasian
XVI Kazakhstan
XVII Central Asian
XVIII Byelorussian
Murmansk
Tallinn
Riga
Leningrad
Vilnius
Arkhangelsk
Lvov
Minsk
Vinnitsa
Kishinev
Kiev
Moscow
Ivanovo
Syktyvkar
Tula
Odessa
Kharkov
Gorky
Dnepropetrovsk
Voronezh
Donetsk
Saratov
Kuibyshev
Perm
Rostov-on-Don
Volga
Sverdlovsk
Volgograd
Chelyabinsk
Urals
Tbilisi
Yerevan
Baku
Aktyubinsk
Ob
Lena
Yenisei
Irtysh
Novosibirsk
Kemerovo
Krasnoyarsk
Irkutsk
Magadan
Amur
Khabarovsk
Vladivostok
Tselinograd
Karaganda
Semipalatinsk
Ust-Kamenogorsk
Syr Darya
Amu Darya
Chimkent
Tashkent
Alma-Ata

PLANNED DISTRIBUTION OF INDUSTRIAL PRODUCTION IN ORDER TO BRING IT CLOSER TO RAW MATERIAL AND FUEL SOURCES

An example of the planned distribution of industrial production in the USSR is the creation of large industrial centers and complexes of heavy industry in many of the country's economic areas: the North-West (Kirovsk, Kandalaksha, Vorkuta), the Urals (Magnitogorsk, Chelyabinsk, Nizhny Tagil), Western and Eastern Siberia (Novosibirsk, Novokuznetsk, Kemerovo, Krasnoyarsk, Irkutsk, Bratsk), Kazakhstan (Karaganda, Rudny, Balkhash, Dzhezkazgan).

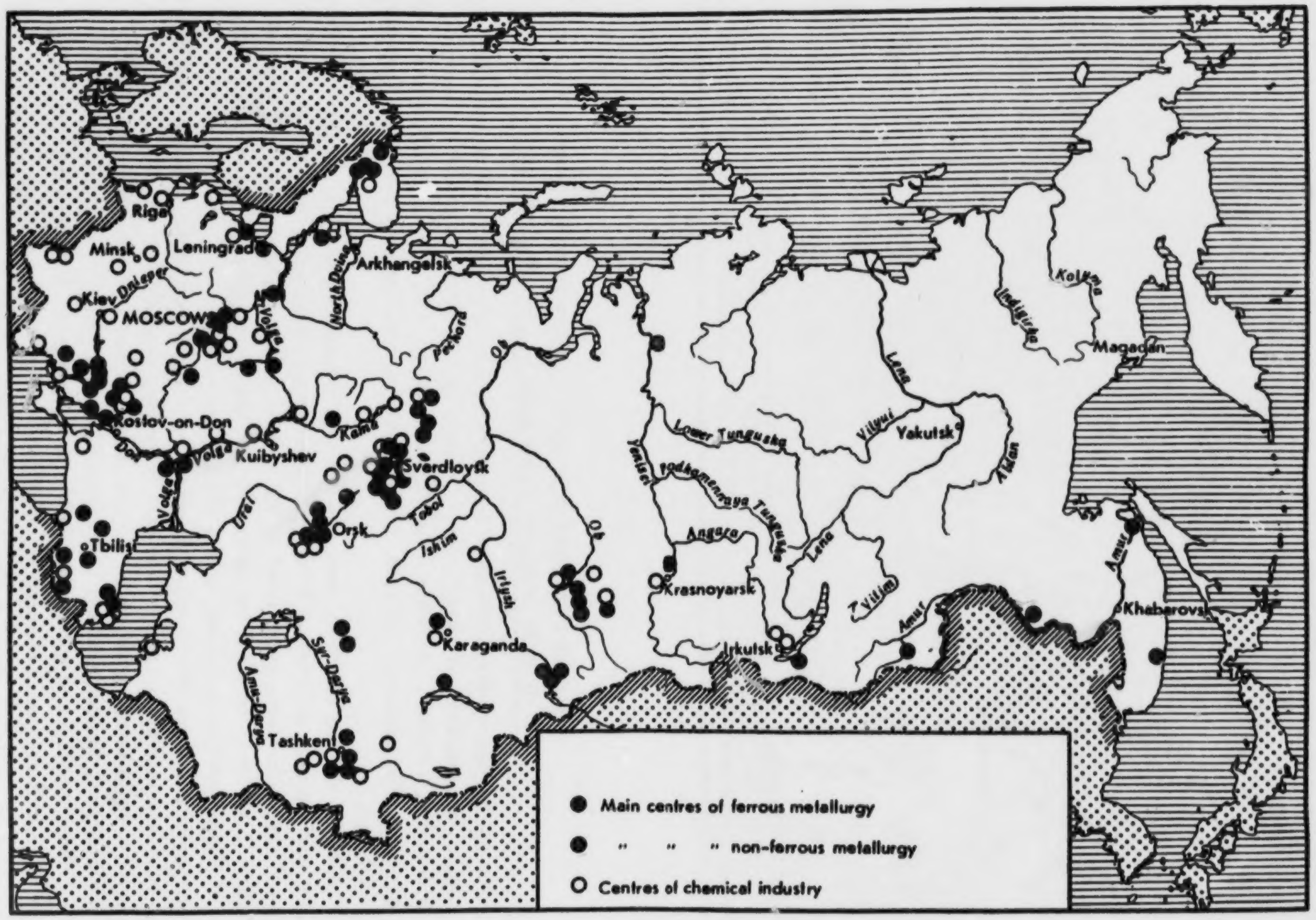
Large industrial systems are being created - Kustanai, Pavlodar-Ekibastuz, Achinsk-Krasnoyarsk, Bratsk-Taishet and a number of others. Ferrous and non-ferrous metallurgy, pulp and paper, hydrolysis and saw-milling industries are being established in the Bratsk-Taishet industrial system. The Achinsk-Krasnoyarsk industrial system is becoming one of the largest centers of aluminum and chemical industries, and production of ferrous metals, cellulose, paper, and oil products.

Construction of the third metallurgical base has been launched in Siberia, and a new base of ferrous metallurgy, using the enormous local iron and coal resources, has been created in Kazakhstan. A high-capacity power system is being organized in the same areas. Non-ferrous metallurgy is being further developed in Kazakhstan, Central Asia and in Transbaikal areas. The pulp and paper, as well as the timber, industries are being developed at a fast rate in the forest areas of Siberia and the Far East.

Ferrous metallurgy is also developing in the European part of the country by utilizing the enormous iron ore resources of the Kursk Magnetic Anomaly and the Ukrainian deposits. Large new production systems are under construction in the North-West, along the Volga, in the Northern Caucasus and the Ukraine.

(After A. Lavrishchev, "Economic Geography
of the U.S.S.R.", Moscow 1969)

THE MAJOR INDUSTRIAL CENTERS OF THE USSR


Riga
Minsk
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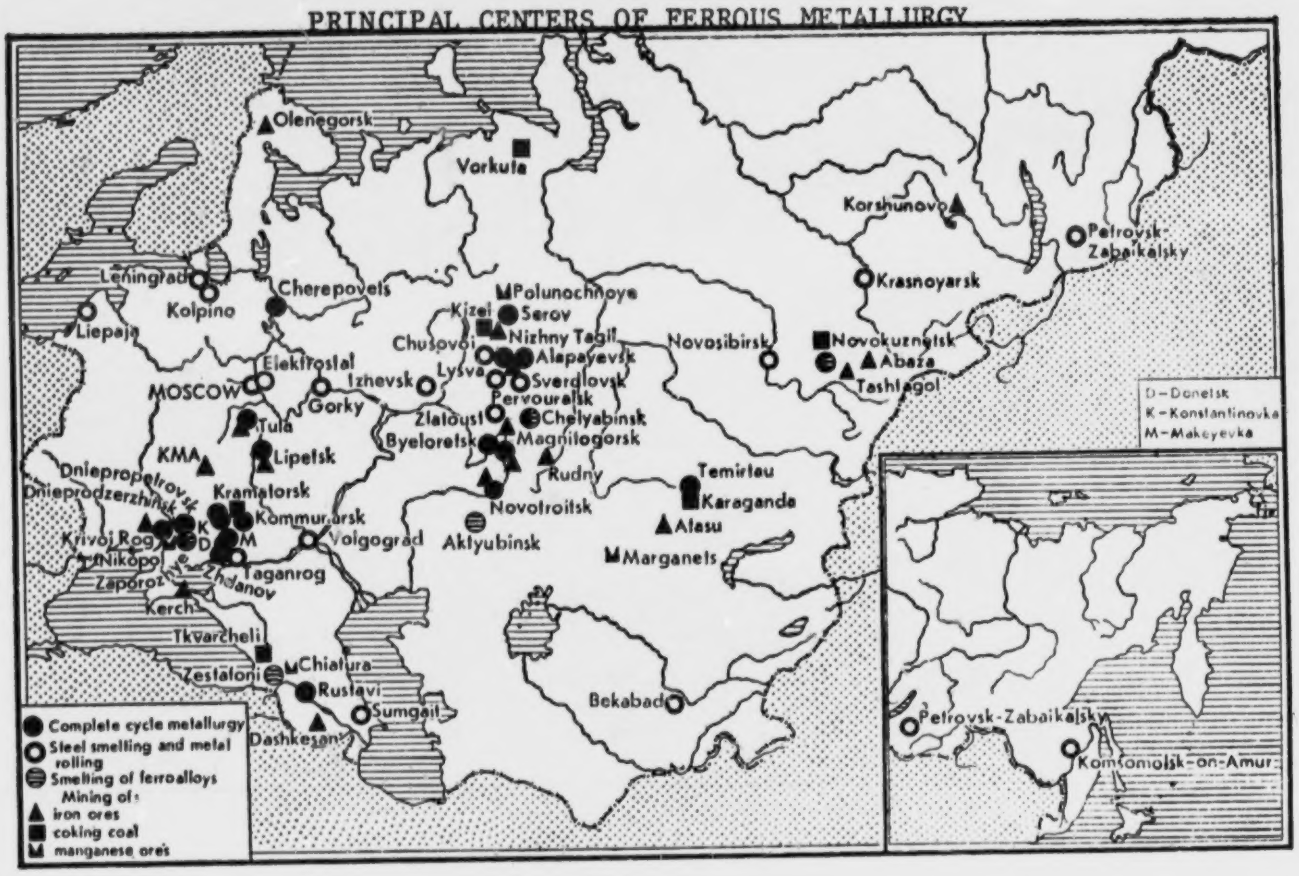
Kiev
Dnieper
MOSCOW
Volga
North Dvina
Arkhangelsk
Pechora
Ob
Rostov-on-Don
Don
Volga
Kuibyshev
Kama
Sverdlovsk
Volga
Ural
Orsk
Tbilisi
Tobol
Ishim
Irtysh
Karaganda
Amu-Darya
Syr-Darya
Tashkent
Yenisei
Lower Tunguska
Podkamennaya Tunguska
Angara
Krasnoyarsk
Irkutsk
Lena
Vilyui
Yakutsk
Aldan
Vitim
Amur
Indigirka
Kolyma
Magadan
Amur
Khabarovsk
● Main centres of ferrous metallurgy
● " " " non-ferrous metallurgy
○ Centres of chemical industry

(After A. Efimov, "Soviet Industry", Moscow 1968)

PRINCIPAL CENTERS OF FERROUS METALLURGY


Olenegorsk
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Korshunovo
Petrovsk-Zabaikalsky
Krasnoyarsk
Leningrad
Kolpino
Cherepovets
Liepaja
Polunochnoye
Kizel
Serov
Chusovoi
Nizhny Tagil
Alapayevsk
Novosibirsk
Novokuznetsk
Abaza
Tashtagol
Elektrostal
MOSCOW
Gorky
Izhevsk
Lysva
Sverdlovsk
Pervouralsk
Zlatoust
Chelyabinsk
Byeloretsk
Magnitogorsk
Tula
KMA
Lipetsk
Dniepropetrovsk
Dnieprodzerzhinsk
Kramatorsk
Kommunarsk
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Zaporozhye
Zhdanov
Taganrog
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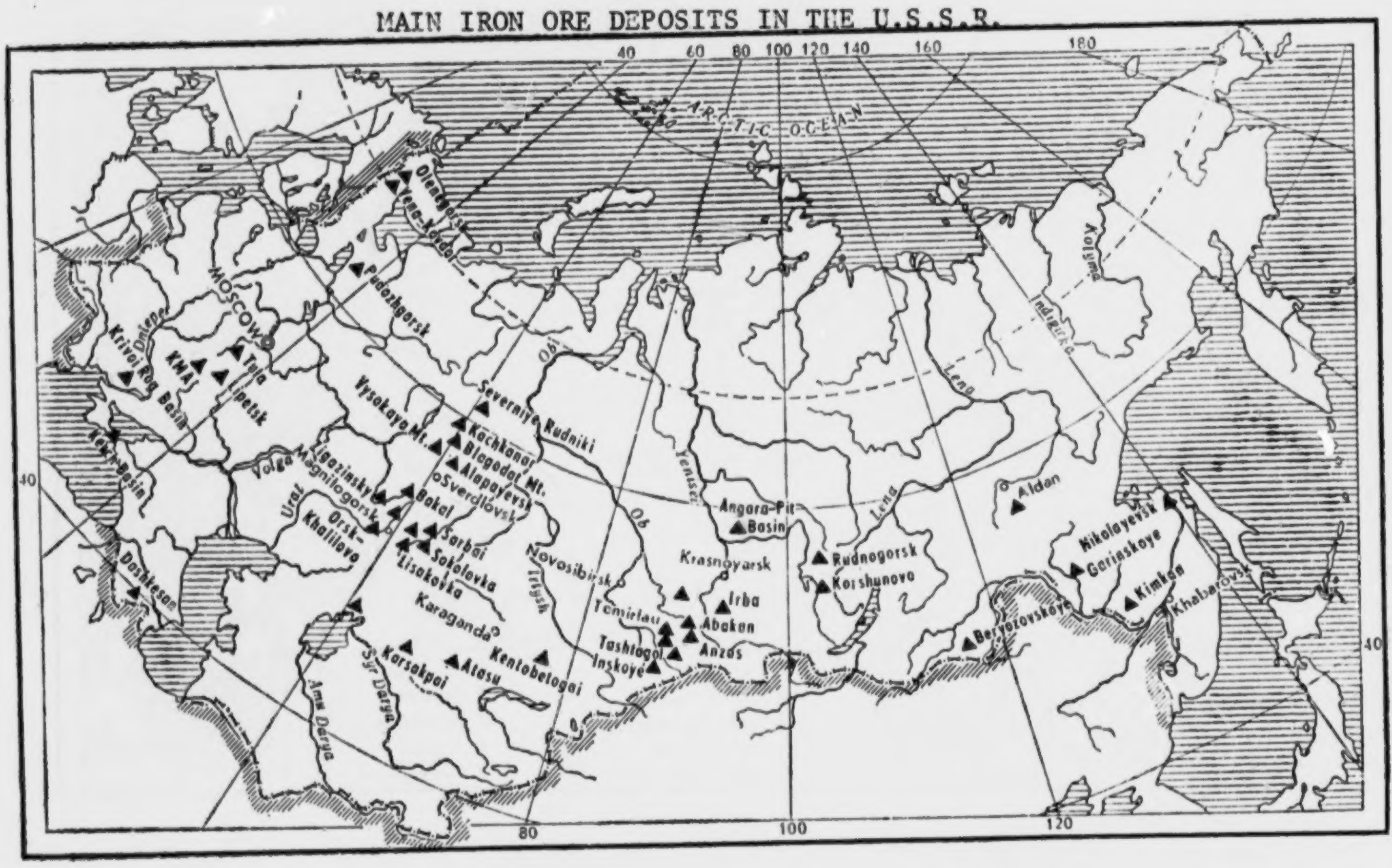
Rudny
Novotroitsk
Aktyubinsk
Temirtau
Karaganda
Atasu
Marganets
Kerch
Tkvarcheli
Zestafoni
Chiatura
Rustavi
Sumgait
Dashkesan
Bekabad
Komsomolsk-on-Amur
D—Donetsk
K—Konstantinovka
M—Makeyevka
● Complete cycle metallurgy
○ Steel smelting and metal rolling
⊜ Smelting of ferroalloys
Mining of:
▲ iron ores
■ coking coal
M manganese ores

MAIN IRON ORE DEPOSITS IN THE U.S.S.R.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Olenegorsk
Yena-Kovdor
Pudozhgorsk
MOSCOW
Dnieper
Krivoi Rog Basin
KMA
Tula
Lipetsk
Kerch Basin
Volga
Dashkesan
Severniye Rudniki
Vysokaya Mt.
Kachkanar
Blagodat Mt.
Alapayevsk
Sverdlovsk
Bakal
Magnitogorsk
Ural
Kurgazinsky
Orsk-Khalilovo
Sarbai
Sokolovka
Lisakovka
Karaganda
Kentobetogai
Atasu
Karsakpai
Syr Darya
Amu Darya
Ob
Irtysh
Novosibirsk
Temirtau
Tashtagol
Inskoye
Anzas
Abakan
Irba
Yenisei
Krasnoyarsk
Angara-Pit Basin
Rudnogorsk
Korshunovo
Lena
Aldan
Indigirka
Kolyma
Nikolayevsk
Gerinskoye
Kimkan
Khabarovsk
Beryozovskoye
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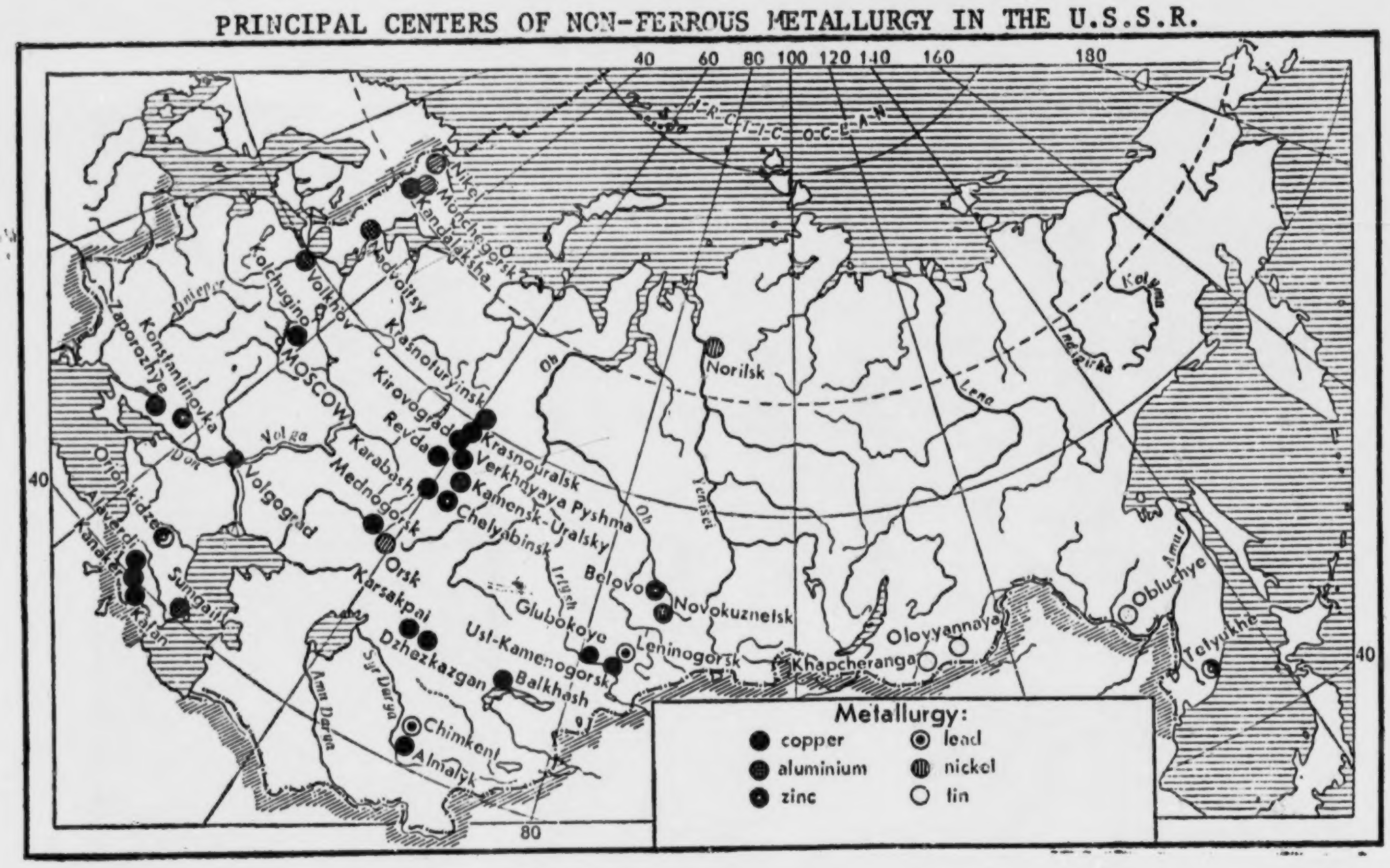
(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

PRINCIPAL CENTERS OF NON-FERROUS METALLURGY IN THE U.S.S.R.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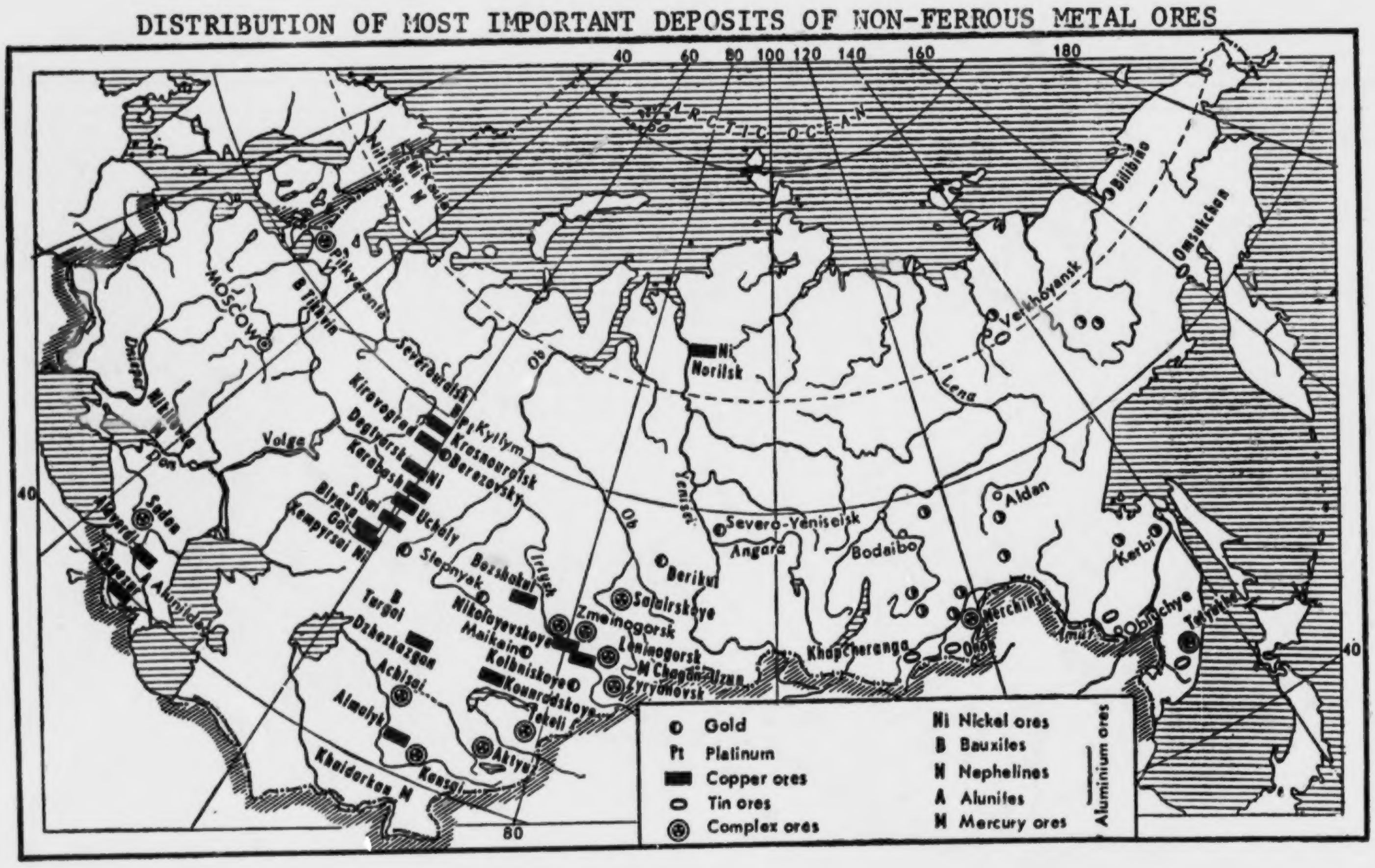
A-R-C-T-I-C O-C-E-A-N
Nikel
Monchegorsk
Kandalaksha
Nadvoitsy
Volkhov
Kolchugino
MOSCOW
Krasnoturyinsk
Kirovograd
Krasnouralsk
Revda
Verkhnyaya Pyshma
Karabash
Kamensk-Uralsky
Mednogorsk
Chelyabinsk
Orsk
Konstantinovka
Zaporozhye
Dnieper
Volga
Don
Volgograd
Ordzhonikidze
Alaverdi
Kanaker
Kafan
Sumgait
Karsakpai
Dzhezkazgan
Balkhash
Chimkent
Almalyk
Ust-Kamenogorsk
Glubokoye
Leninogorsk
Belovo
Novokuznetsk
Irtysh
Ob
Yenisei
Norilsk
Lena
Kolyma
Indigirka
Amur
Obluchye
Oloyyannaya
Khapcheranga
Tetyukhe
Amu Darya
Syr Darya
Metallurgy:
copper
aluminium
zinc
lead
nickel
tin

DISTRIBUTION OF MOST IMPORTANT DEPOSITS OF NON-FERROUS METAL ORES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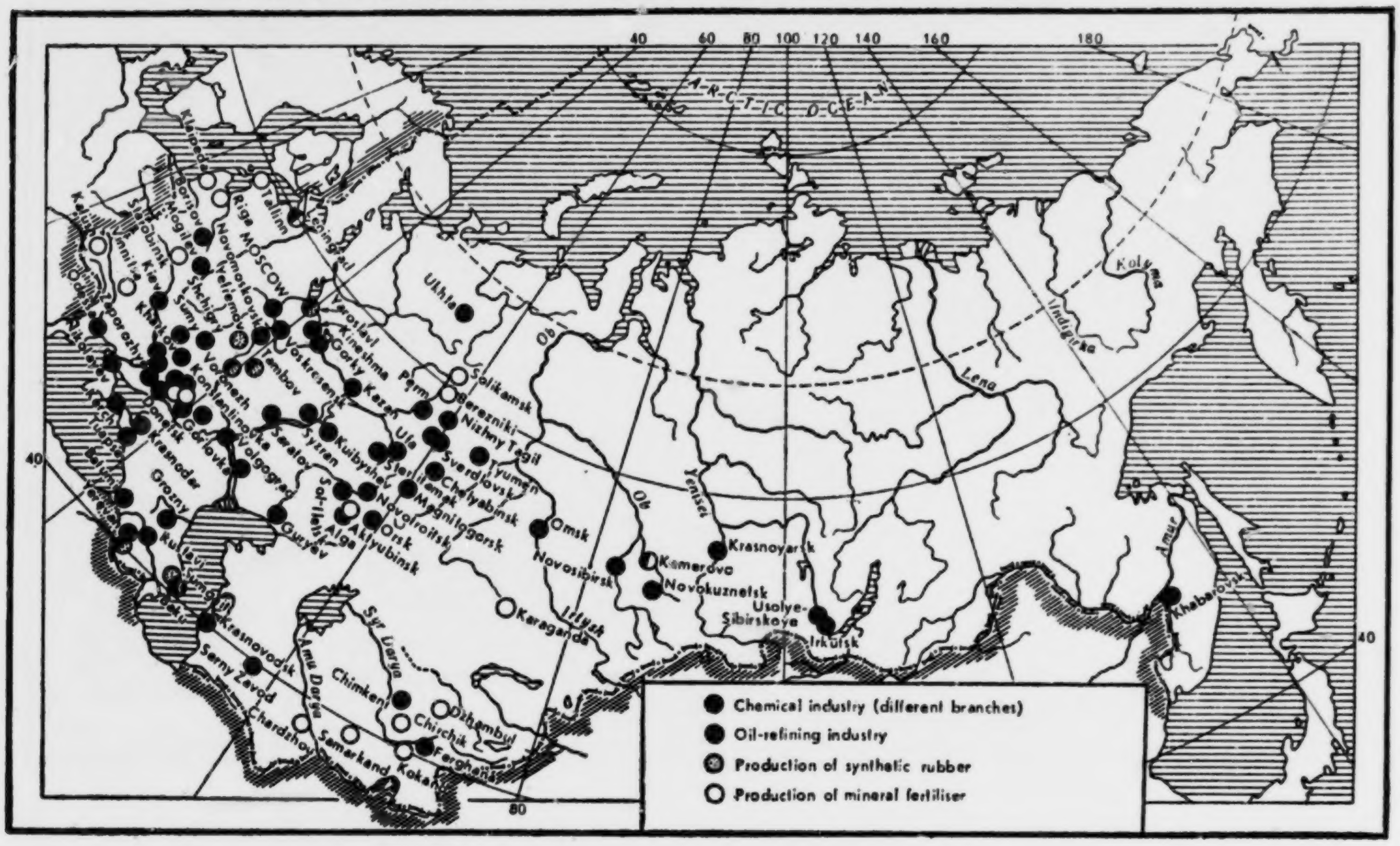
Dnieper
Nikopol
Volga
Don
Boksitogorsk
Timan
Severouralsk
Kirovograd
Krasnouralsk
Degtyarsk
Berezovsky
Karabash
Sibai
Birsyak
Gai
Kempyrsai
Uchaly
Kytlym
Stepnyak
Turgai
Dzhezkazgan
Bozshakol
Irtysh
Nikolayevskoye
Maikain
Kolbinskoye
Kounradskoye
Tekeli
Achisai
Almalyk
Kansai
Aktyuz
Khaidarkan
Zmeinogorsk
Leninogorsk
Chagan-Uzun
Zyryanovsk
Salairskoye
Alaverdi
Kafan
Zaglik
Sadon
Norilsk
Severo-Yeniseisk
Angara
Berikul
Bodaibo
Khapcheranga
Nerchinsk
Aldan
Verkhoyansk
Bilibino
Omsukchan
Kerbi
Obluchye
Tetyukhe
Yenisei
Ob
Lena
Gold
Platinum
Copper ores
Tin ores
Complex ores
Nickel ores
Bauxites
Nephelines
Alunites
Mercury ores
Aluminium ores

(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

PRINCIPAL CENTERS OF THE CHEMICAL INDUSTRY IN THE U.S.S.R.


A-R-C-T-I-C O-C-E-A-N
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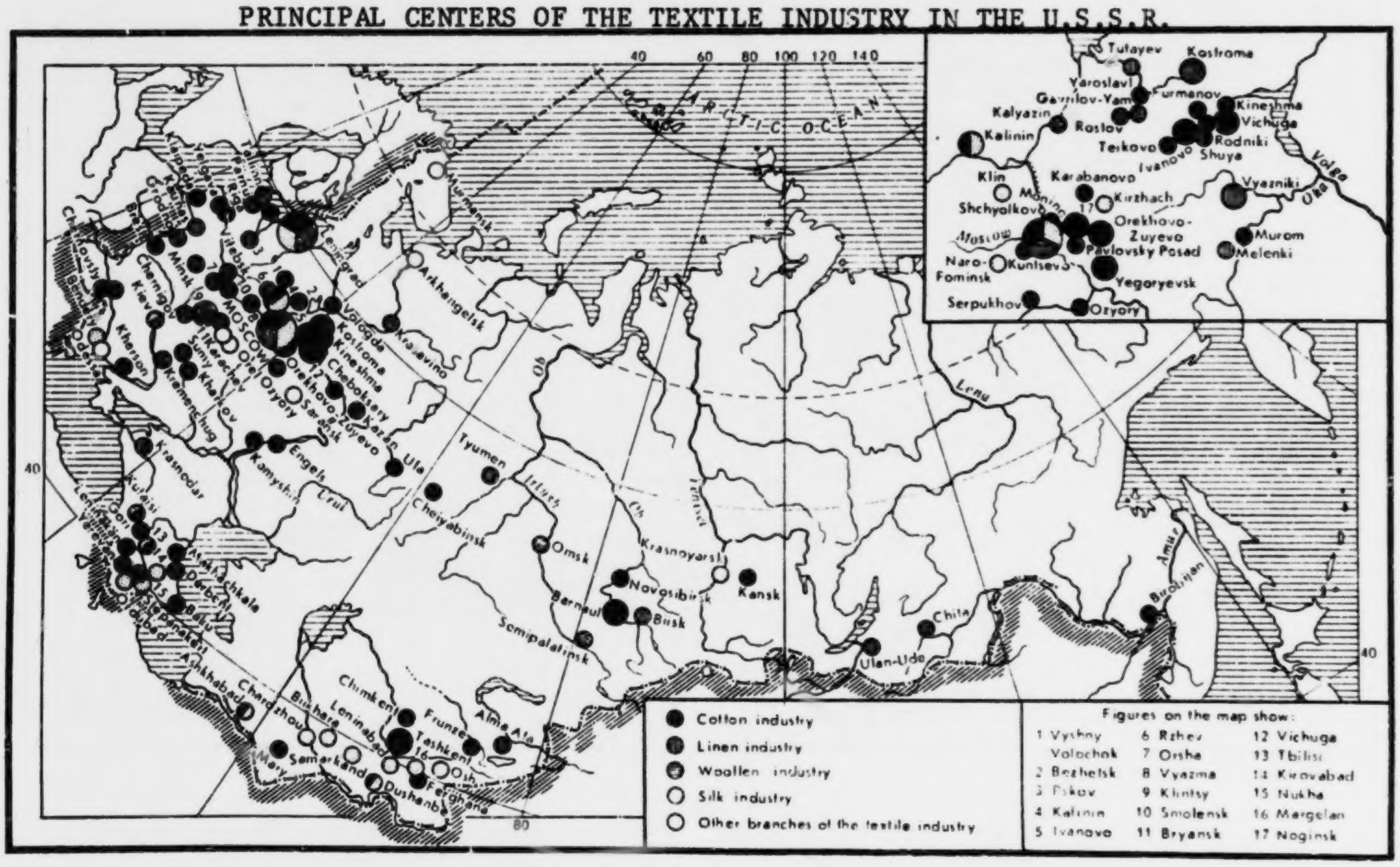
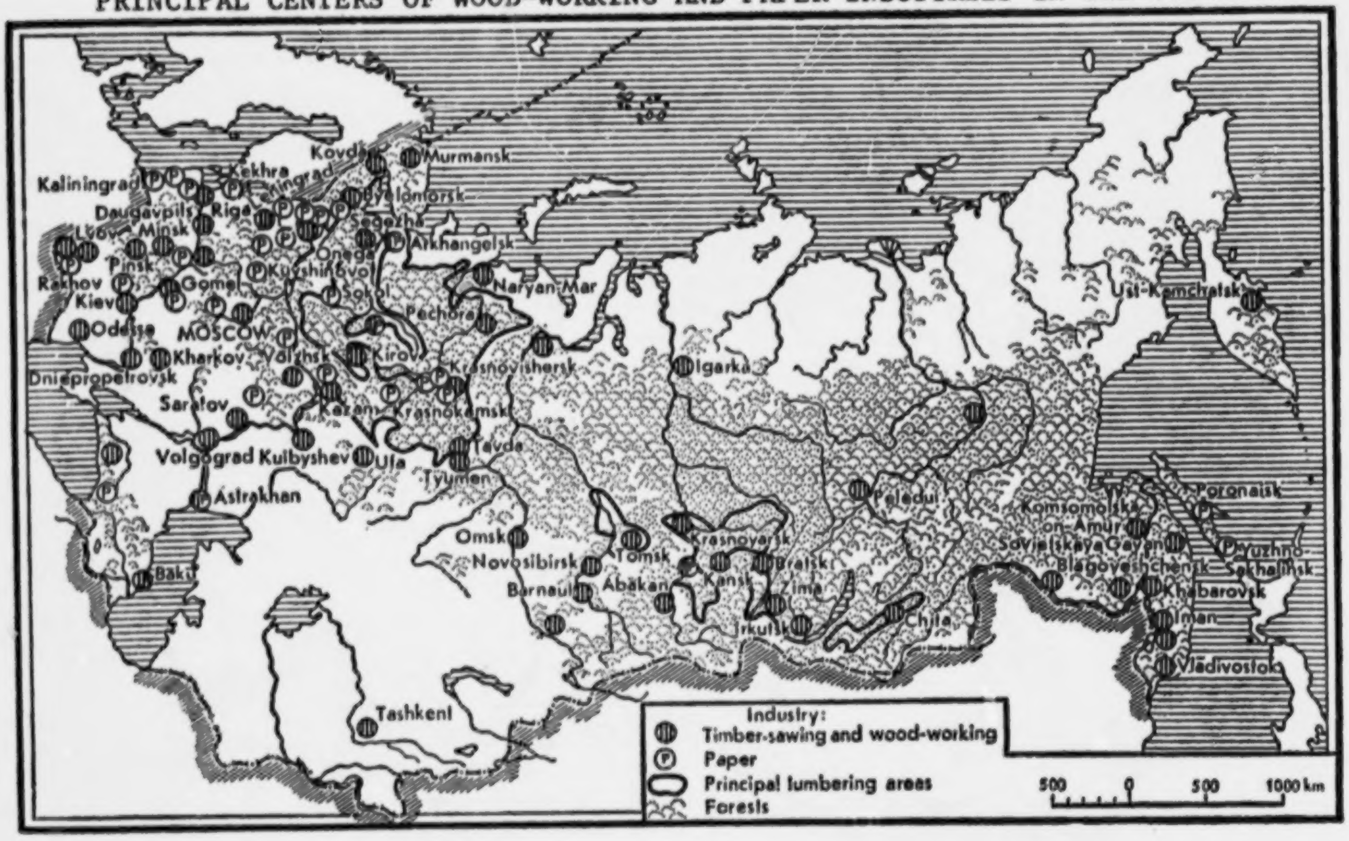
160
180
MOSCOW
Riga
Tallin
Leningrad
Yaroslavl
Kineshma
Gorky
Tambov
Voskresensk
Kazan
Perm
Solikamsk
Berezniki
Nizhny Tagil
Ufa
Sverdlovsk
Tyumen
Chelyabinsk
Sterlitamak
Kuibyshev
Syzran
Novokuibyshevsk
Novotroitsk
Orsk
Magnitogorsk
Aktyubinsk
Volgograd
Saratov
Gurev
Krasnodar
Grozny
Kutaisi
Baku
Krasnovodsk
Cherdzhou
Samarkand
Kokand
Ferghana
Chirchik
Dzhambul
Chimkent
Karaganda
Omsk
Novosibirsk
Kemerovo
Novokuznetsk
Krasnoyarsk
Usolye-Sibirskoye
Irkutsk
Khabarovsk
Ukhta
Ob
Irtysh
Yenisei
Lena
Indigirka
Kolyma
Amur
Syr Darya
Amu Darya
Chemical industry (different branches)
Oil-refining industry
Production of synthetic rubber
Production of mineral fertiliser

PRINCIPAL CENTERS OF THE TEXTILE INDUSTRY IN THE U.S.S.R.

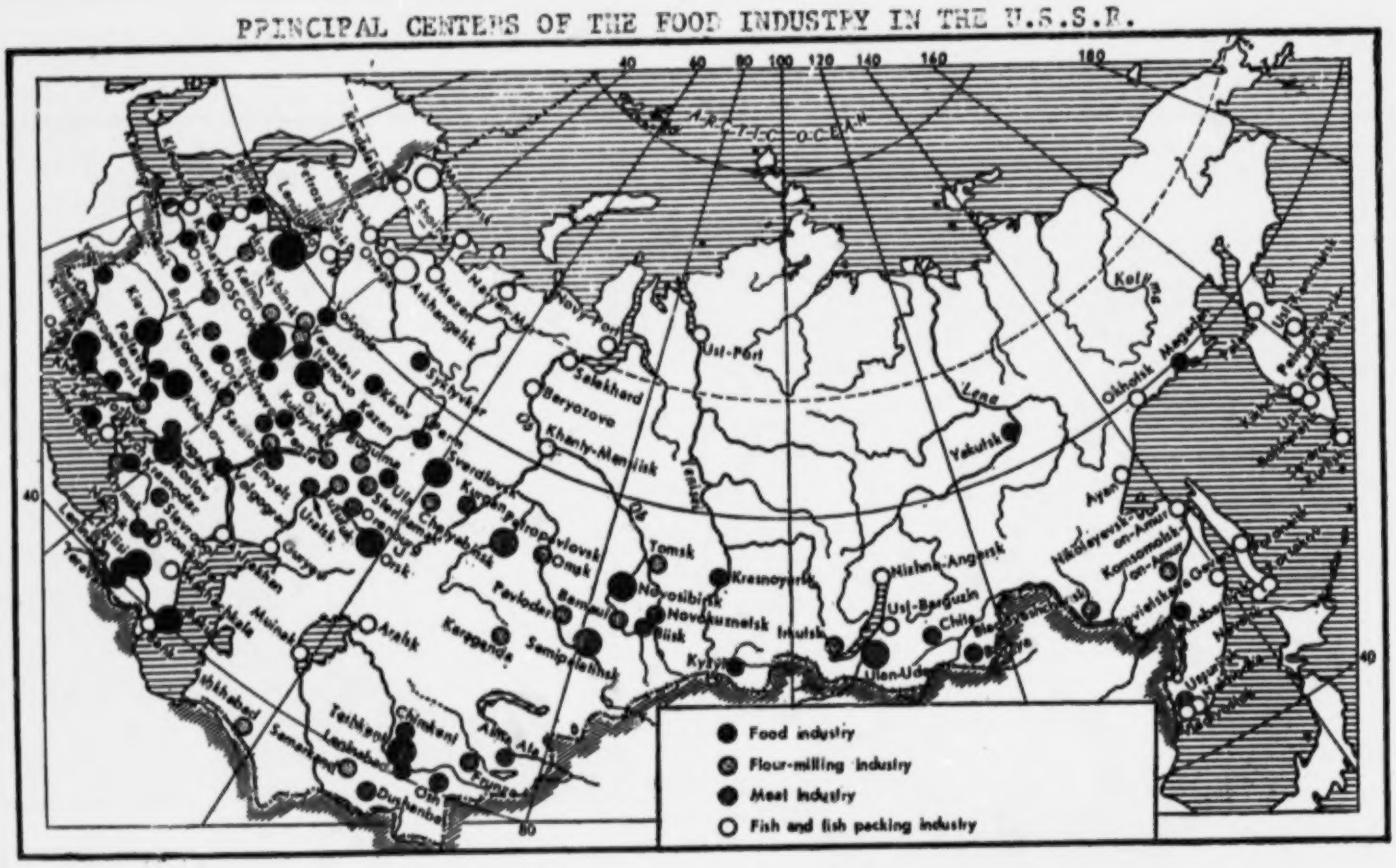

A-R-C-T-I-C O-C-E-A-N
40
60
80
100
120
140
Tutayev
Kostroma
Yaroslavl
Gavrilov-Yam
Furmanov
Kalyazin
Rostov
Kineshma
Vichuga
Kalinin
Teikovo
Rodniki
Ivanovo
Shuya
Klin
Karabanovo
Kirzhach
Vyazniki
Shchyolkovo
Monino
Orekhovo-Zuyevo
Moscow
Pavlovsky Posad
Murom
Melenki
Naro-Fominsk
Kuntsevo
Yegoryevsk
Serpukhov
Ozyory
Oka
Volga
Leningrad
Arkhangelsk
Vologda
Kostroma
Kineshma
Cheboksary
Kazan
Ufa
Orekhovo-Zuyevo
Saransk
Minsk
Chernigov
Kiev
Kherson
Kremenchug
Orel
Ozyory
Engels
Kamyshin
Krasnodar
Kutaisi
Baku
Makhachkala
Ashkhabad
Chardzhou
Bukhara
Samarkand
Dushanbe
Leninabad
Tashkent
Osh
Ferghana
Chimkent
Frunze
Alma Ata
Chelyabinsk
Tyumen
Omsk
Barnaul
Semipalatinsk
Novosibirsk
Biisk
Krasnoyarsk
Kansk
Ulan-Ude
Chita
Birobidzhan
Ob
Irtysh
Yenisei
Lena
Amur
Ural
Cotton industry
Linen industry
Woollen industry
Silk industry
Other branches of the textile industry
Figures on the map show:
1 Vyshny Volochok
2 Bezhetsk
3 Pskov
4 Kalinin
5 Ivanovo
6 Rzhev
7 Orsha
8 Vyazma
9 Klintsy
10 Smolensk
11 Bryansk
12 Vichuga
13 Tbilisi
14 Kirovabad
15 Nukha
16 Margelan
17 Noginsk

(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

PRINCIPAL CENTERS OF WOOD-WORKING AND PAPER INDUSTRIES IN THE U.S.S.R.

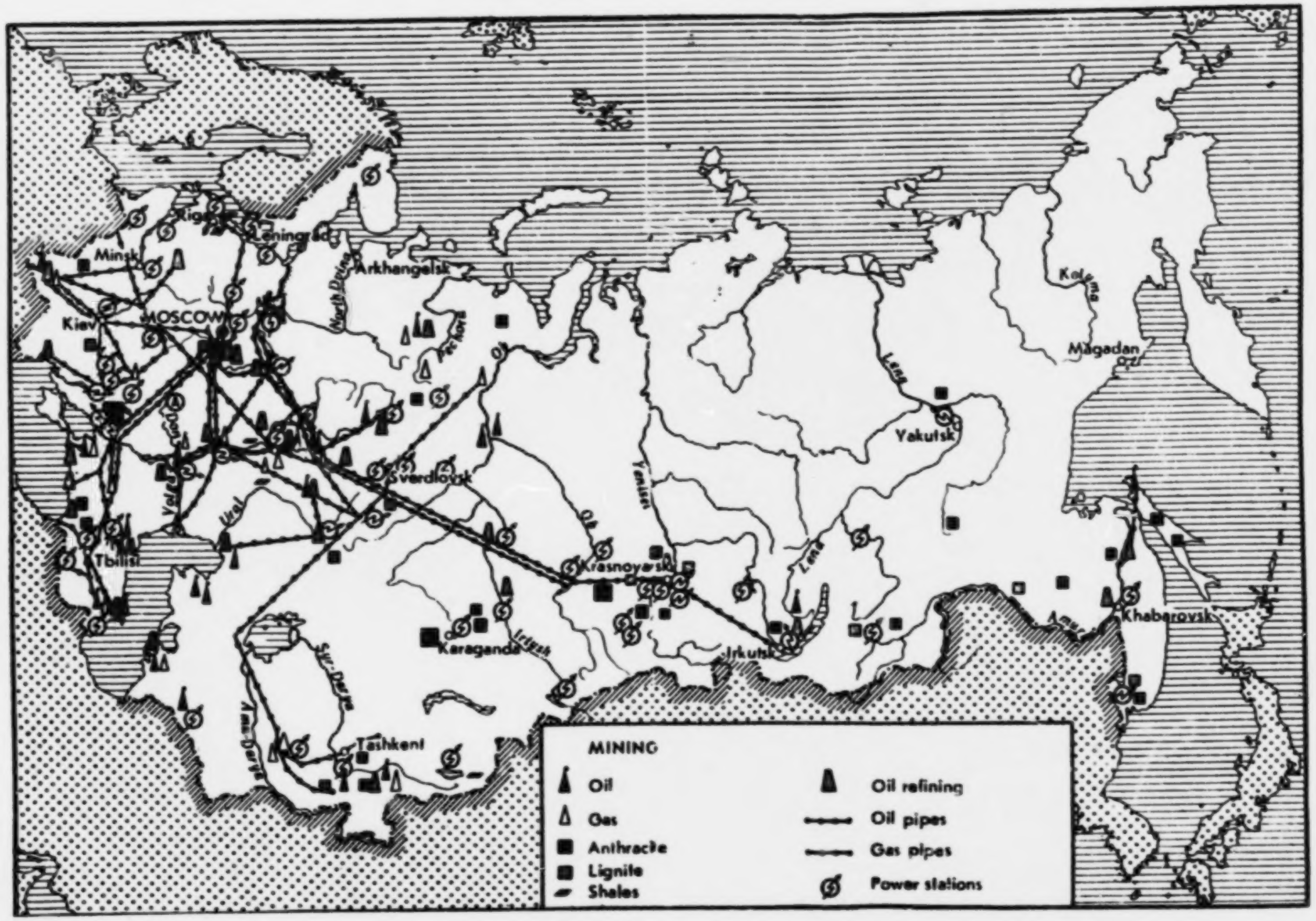

Industry:
Ⓘ Timber-sawing and wood-working
Ⓟ Paper
Principal lumbering areas
Forests
500 0 500 1000 km
Kaliningrad
Kekhra
Leningrad
Kovdor
Murmansk
Daugavpils
Riga
Belomorsk
Lvov
Minsk
Segezha
Arkhangelsk
Pinsk
Onega
Rakhov
Gomel
Kotlas
Naryan-Mar
Kiev
Sokol
Pechora
Odessa
MOSCOW
Kharkov
Volzhsk
Kirov
Krasnovishersk
Igarka
Dniepropetrovsk
Kazan
Krasnokamsk
Saratov
Tavda
Volgograd
Kuibyshev
Ufa
Tyumen
Astrakhan
Omsk
Novosibirsk
Tomsk
Krasnoyarsk
Barnaul
Abakan
Kansk
Bratsk
Zima
Irkutsk
Chita
Baku
Tashkent
Yeniseisk
Ust-Kamchatsk
Komsomolsk-on-Amur
Sovietskaya Gavan
Poronaisk
Yuzhno-Sakhalinsk
Blagoveshchensk
Khabarovsk
Iman
Vladivostok

PRINCIPAL CENTERS OF THE FOOD INDUSTRY IN THE U.S.S.R.


ARCTIC OCEAN
40
60
80
100
120
140
160
180
● Food industry
◉ Flour-milling industry
● Meat industry
○ Fish and fish packing industry
MOSCOW
Arkhangelsk
Mezen
Naryan-Mar
Salekhard
Beryozovo
Khanty-Mansiisk
Ust-Port
Syktyvkar
Kirov
Perm
Sverdlovsk
Kazan
Kurgan
Petropavlovsk
Chelyabinsk
Orenburg
Orsk
Omsk
Tomsk
Krasnoyarsk
Novosibirsk
Novokuznetsk
Barnaul
Biisk
Pavlodar
Semipalatinsk
Karaganda
Kyzyl
Irkutsk
Nizhne-Angarsk
Ust-Barguzin
Ulan-Ude
Chita
Yakutsk
Lena
Okhotsk
Magadan
Ayan
Nikolayevsk-on-Amur
Komsomolsk-on-Amur
Volgograd
Astrakhan
Guryev
Uralsk
Aralsk
Muinak
Krasnodar
Stavropol
Tashkent
Chimkent
Alma-Ata
Frunze
Samarkand
Dushanbe
Ashkhabad
Kharkov
Kiev
Voronezh
Saratov
Kuibyshev
Ufa
Kemerovo
40
80

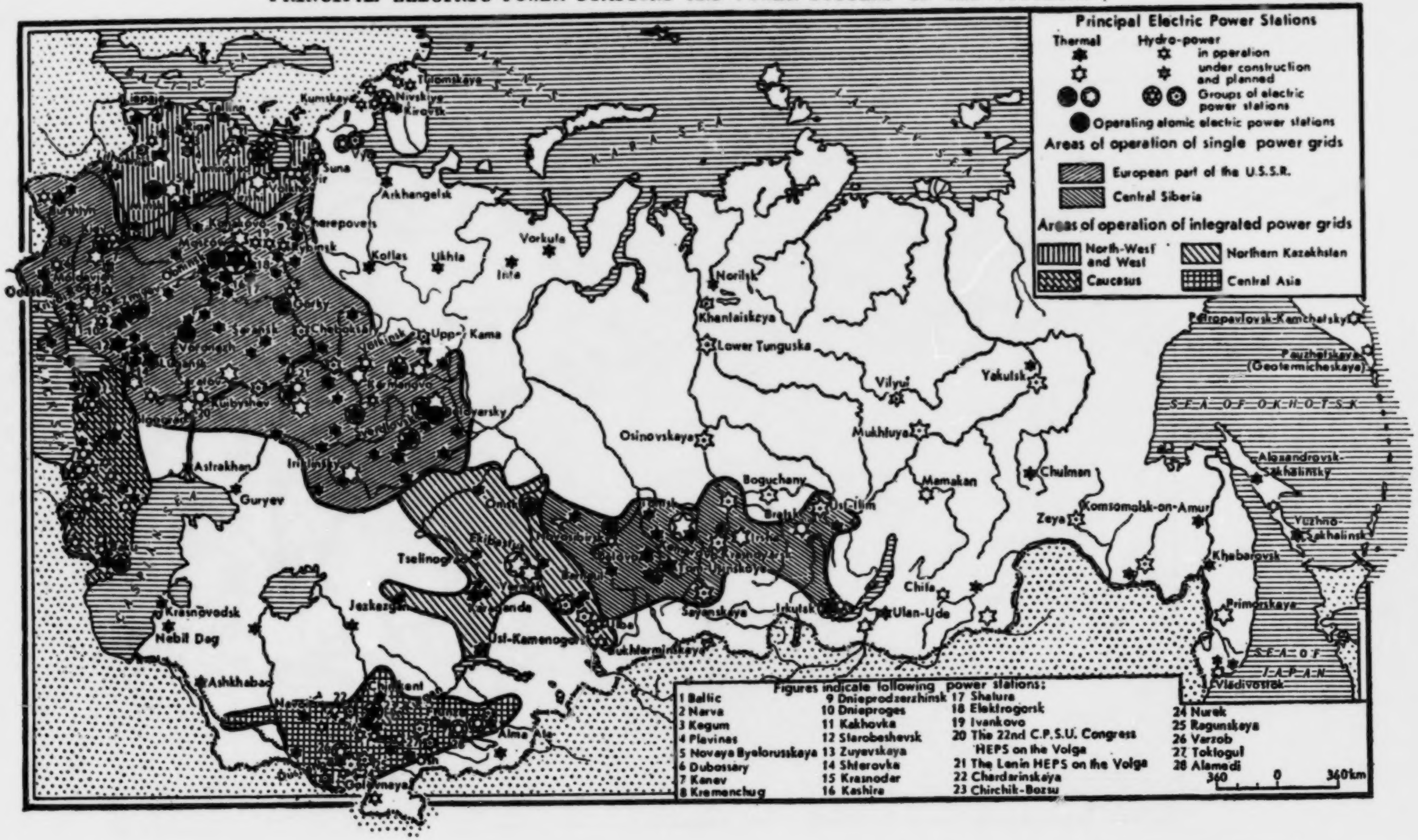
(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

THE MAIN MINING CENTERS OF THE USSR


Riga
Leningrad
Minsk
Kiev
MOSCOW
Arkhangelsk
North Dvina
Pechora
Volga
Don
Ural
Sverdlovsk
Tbilisi
Ob
Yenisei
Krasnoyarsk
Karaganda
Irtysh
Syr-Darya
Amu-Darya
Tashkent
Irkutsk
Lena
Yakutsk
Kolyma
Magadan
Amur
Khabarovsk
MINING
Oil
Gas
Anthracite
Lignite
Shales
Oil refining
Oil pipes
Gas pipes
Power stations

(After A. Efimov, "Soviet Industry", Moscow 1968)

PRINCIPAL ELECTRIC POWER STATIONS AND POWER SYSTEMS IN THE U.S.S.R.


Principal Electric Power Stations
Thermal
Hydro-power
in operation
under construction and planned
Groups of electric power stations
Operating atomic electric power stations
Areas of operation of single power grids
European part of the U.S.S.R.
Central Siberia
Areas of operation of integrated power grids
North-West and West
Northern Kazakhstan
Caucasus
Central Asia
Figures indicate following power stations:
1 Baltic
2 Narva
3 Kegum
4 Plavinas
5 Novaya Byelorusskaya
6 Dubossary
7 Kanev
8 Kremenchug
9 Dnieprodzerzhinsk
10 Dnieproges
11 Kakhovka
12 Starobeshevsk
13 Zuyevskaya
14 Shterovka
15 Krasnodar
16 Kashira
17 Shatura
18 Elektrogorsk
19 Ivankovo
20 The 22nd C.P.S.U. Congress HEPS on the Volga
21 The Lenin HEPS on the Volga
22 Chardarinskaya
23 Chirchik-Bozsu
24 Nurek
25 Ragunskaya
26 Varzob
27 Toktogul
28 Alamedi
360
0
360km
BARENTS SEA
KARA SEA
LAPTEV SEA
SEA OF OKHOTSK
SEA OF JAPAN
Tulomaskaya
Kumskaya
Nivskiye
Kirovsk
Tallinn
Riga
Suna
Arkhangelsk
Cherepovets
Rybinsk
Kotlas
Ukhta
Inta
Vorkuta
Moscow
Gorky
Cheboksary
Saratov
Voronezh
Kuibyshev
Volgograd
Upper Kama
Votkinsk
Sverdlovsk
Astrakhan
Guryev
Irtyshsky
Omsk
Ekibastuz
Tselinograd
Karaganda
Jezkazgan
Krasnovodsk
Nebit Dag
Ashkhabad
Tashkent
Alma-Ata
Ust-Kamenogorsk
Bukhtarminskaya
Novosibirsk
Krasnoyarsk
Sayanskaya
Irkutsk
Bratsk
Ust-Ilim
Boguchany
Osinovskaya
Norilsk
Khantaiskaya
Lower Tunguska
Vilyui
Mukhtuya
Yakutsk
Mamakan
Chulman
Chita
Ulan-Ude
Zeya
Komsomolsk-on-Amur
Khabarovsk
Primorskaya
Vladivostok
Yuzhno-Sakhalinsk
Alexandrovsk-Sakhalinsky
Petropavlovsk-Kamchatsky
Pauzhetskaya (Geotermicheskaya)
Odessa
Oplavnaya

(After A. Lavrishchev, "Economic Geography of the U.S.S.R.", Moscow 1969)

HOW TO NEUTRALIZE AUTOMOBILE EXHAUST GASES

I. L. Varshavskiy and R. V. Malov

Izdatel'stvo "Transport"
Moskva, 1968
p. 3-126

Introduction

The 20th century is rightly called the century of cybernetics, atomic energy, and space flights, but it remains first and foremost the century of the automobile. There may now be no corner left in the world without automobiles of the most different types, used for the most diverse purposes.

The production of automobiles increases steadily. New, improved models are being built for use in the most varied areas of the economy.

The world automobile pool of the capitalist countries of 1 January 1966 was characterized by the data listed in Table 1.

Table 1

Continent	Automobile Type			Total
	Passenger	Trucks	Buses	
Africa . . .	2.412.200	909.200	73.600	3.395.000
Oceania . . .	3.649.800	1.044.900	21.500	4.716.200
Asia	4.235.300	5.598.900	367.400	10.201.000
Western Europe	43.147.400	7.121.500	314.000	50.582.900
America . . .	85.275.900	18.393.200	558.300	104.230.200
Total . . .	138.747.600	33.070.700	1.334.800	173.153.100

In 1970, the Soviet Union is planning to raise its production to 600,000-650,000 trucks and 700,000-800,000 passenger cars, i.e., more than double the 1965 output.

The time has come to give serious consideration to the question of whether the increase in the number of automobiles is dangerous for man, considering the fact that the exhaust gases of automobile engines contain large amounts of poisonous substances. How and to what extent is the atmosphere of populated areas and cities polluted by the toxic components of exhaust gases and to what extent is this harmful to man?

The degree of atmospheric pollution by exhaust gases in cities may be estimated from the following data.

In the major cities of the U.S.A., the average concentration of carbon monoxide in atmospheric air is 30-50 mg/m^3.* Of this, 60% is produced by automobile engines. The combustion of one ton of fuel in the engine's cylinders, depending on the operating conditions, type of engine and its adjustment, discharges from 150 to 800 kg of carbon monoxide into the atmosphere.

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* Different standards for the maximum content of toxic substances in the atmosphere have been adopted in different countries. They are also given in different units. Appendix 1 lists the sanitary standards for maximum contents of noxious substances adopted in the USSR and Appendix 2 gives a table for converting these units.

Climatic conditions have different effects on the pollution of air with exhaust gases and in some areas of the world are the cause of great distress for the population. In London, for example, with its frequent fog and total want of wind, several cases of mass poisoning of people by automobile exhausts have been recorded in the last 15 years. One took place toward the end of 1952, when in a matter of a few days about 4000 people died, which considerably exceeded the human losses of the 1866 cholera epidemic and was twice the number of human victims of the tragic eruption of Vesuvius in 79 A.D., which buried the antique cities of Pompeii and Herculaneum.

Over Los Angeles (USA), a haze called smog appears on sunny days. It causes irritation of the eyes and upper respiratory tract in people, destroys the vegetation, and decomposes the rubber of automobile tire casings. The origin of the smog remained a puzzle for a long time, then it was found to be caused by automobile exhaust gases. Under the influence of sunlight, the various components of exhaust gases (C_nH_m-type hydrocarbons) enter into photochemical reactions with air and nitrogen oxides, forming a poisonous fog.

Whereas in the USA one of the factors responsible for the appearance of smog is sunlight, in England, particularly in London, smog occurs on cloudy days. Its nature is different here, but its formation is directly related to the presence in air of a large amount of components of automobile exhausts.

The noxious substances present in exhaust gases are found not only in gas samples taken from the atmosphere of urban thoroughfares but also in the air of the neighboring public gardens and parks. In cities, cases have been reported where carbon monoxide on the fourth-floor balcony of an apartment building was present in a concentration of 28 mg/m^3 and, even in the apartments themselves, in a concentration of 10-20 mg/m^3.

Studies made in the last few years have shown that the exhaust gases contain dangerous carcinogenic substances, in particular, benz(o)pyrene

If the engine operates on ethyl gasoline, lead compounds appear in the exhaust gases. According to experimental data, from 40 to 85% of lead compounds present in ethyl gasolines are discharged into the atmospheric air, with the remainder depositing in the cylinders and exhaust system of the engine. Experiments at the Moscow Scientific Research Institute of Hygiene im. Erisman have shown that the combustion of 1 kg of ethyl gasoline in GAZ-51 automobiles during idling discharges into the atmosphere 0.3 g of lead; at a traveling speed of 15 km/hr, 0.87 g, and at a traveling speed of 40 km/hr, 0.9 g of lead. Long-term studies have shown that in Switzerland, for example, automobiles discharge about 165 tons of lead compounds into the air.

Automobiles and equipment driven by internal combustion engines are used in the mining industry, in shafts, pits, deep quarries, industrial plants, lumber yards, warehouses, tunnels, and other poorly ventilated facilities. Here the purification of exhaust gases becomes an even more acute problem, since, because of the heavy gas contamination of the atmosphere, cases of disruption of work in a number of quarries lasting up to 12 hours or more have occurred. The use of special, powerful ventilating devices for the aeration of these facilities has not yet solved the problem of effective control of engine exhausts.

To eliminate the damage caused by automobile exhausts or decrease it is a most pressing problem and one which today is completely solvable. The efforts of automobile drivers, architects, city planners, medical technicians and staff of the State Automobile Inspection are aimed at creating conditions of automobile operation which will minimize the pollution of urban air with toxic gaseous components of exhausts. In major Soviet cities with a heavy automobile traffic, one-way streets have been introduced, bridges and under passes for pedestrians have been constructed, and major work in urban planting of greenery is being carried out. In Moscow, Leningrad and other large cities, the use of ethyl gasoline has been prohibited. Special devices and systems reducing the formation of noxious substances or neutralizing those already formed are being developed. Much can be done by maintaining the engines in good technical condition and by adjusting and operating them properly.

The program of the CPSU specifies that steps will be taken at the present time to improve further the living conditions in cities and other populated areas, including an all-out war on atmospheric pollution. It is already possible to ensure the presence of pure air in our cities. To this end, it is necessary to determine and enact as soon as possible norms for the maximum content of the main toxic components of exhaust gases; to construct and introduce into the national economy new, improved instruments controlling the operation of engines from the standpoint of the degree of pollution of air with exhaust gases; to use them for the purpose of strictly observing the established norms, and to take a number of steps toward decreasing the toxicity of the aerosols discharged into the atmosphere.

Chapter I

EXHAUST GASES OF AUTOMOBILE ENGINES

1. Combustion of Fuel in Engines

All internal combustion engines are divided into engines with external and internal mixing. They form two groups: the first consists of carburetor engines, and the second, of diesel engines.

In carburetor engines, the burned fuel is fed into the working cylinder in the form of a ready mixture with air. In gas operation, the mixture is formed in a special mixer. In liquid fuel operation (gasoline is usually employed), the mixing takes place by introducing the atomized fuel into a stream of air entering the cylinder. This is done either directly in the intake manifold by means of injectors or in a special device, the carburetor. In all cases, a ready (carburized) mixture of a certain composition enters the cylinder. The mixture is compressed by a piston and ignited by an electric spark plug. The flame spreads from a local, quasi-point source through the entire volume of the fuel-air charge.

All carburetor engines operate on the Otto cycle. Ideally, combustion in these engines should take place at a constant volume of the mixture, i.e., practically instantaneously. Actually, however, the piston is in continuous motion, and the combustion process occupies an appreciable fraction of the cycle. This fraction depends on many factors, but it is determined chiefly by the composition of the mixture.

In describing the mixture composition, use is made of the concept of the excess air coefficient α, representing the ratio of the amount of air actually entering the cylinder to the amount theoretically required for complete combustion of a given amount of fuel.

Experiments have shown that, other conditions being equal, the maximum combustion rate, takes place at $\alpha = 0.85-0.9$. Thus, in order to bring the actual working cycle of an engine as close as possible to the ideal Otto cycle, i.e., to increase the combustion rate, the excess air coefficient should be within the indicated range. Then the engine power reaches maximum values, but the fuel combustion takes place with an insufficient amount of oxygen. As a result, one finds that it is the working cycle of carburetor engines that predetermines an incomplete combustion of fuel.

The fuels used in engines constitute a complex mixture of the most diverse compounds of carbon and hydrogen referred to by the collective name of hydrocarbons. An insufficient amount of oxygen during oxidation causes the presence of toxic products of incomplete fuel combustion in the exhaust gases: carbon monoxide (CO), oxygen-containing organic compounds such as aldehydes (formaldehyde, acetaldehyde, acrolein, etc.), hydrocarbons in their initial form (ethane, ethylene, propane, isobutane, acetylene, etc.), carbon black, and others.

It should not be assumed that when $a = 1$ or even $a > 1$, no products of incomplete combustion will be formed. The brief time interval occupied by the combustion process, the presence in the working mixture of gases left over from the preceding cycle which prevent the access of oxygen to the fuel molecules, and other factors prevent the complete combustion of fuel to the end products. As a result, carbon monoxide alone is present in amounts of up to 12% by volume in the exhaust gases of carburetor engines under certain operating conditions.

High temperatures and pressures are generated in the engine cylinders during the combustion of fuel. The nitrogen present in the composition of air does not remain inert under these conditions. After the bulk of the fuel has burned, it begins to react with the residual oxygen, forming nitrogen oxides, which also are strong toxic substances.

All liquid fuels including gasolines contain a certain amount of sulfur. According to GOST (All-Union State Standard) 2086-56, for example, up to 0.10% sulfur is allowed in a-74 gasoline, and up to 0.15% in A-66, AZ-66, A-72 and A-76 gasolines. If the gasolines are produced by refineries having no sulfur-removing equipment, GOST permits a sulfur content of up to 0.3% for A-66 and AZ-66 gasolines. The sulfur present in the fuels reacts with oxygen and hydrogen, forming sulfur dioxide and hydrogen sulfide, which are toxic.

The process of fuel combustion may proceed under two typical conditions: normal and knocking. During knocking, near the walls of the cylinder the combustion occurs almost instantaneously, causing an abrupt increase followed by strong fluctuations of the pressure. As a result, a characteristic knock appears in the engine, and the content of nitrogen oxide in the exhaust gases increases sharply. The probability of knocking may be decreased by lowering the compression ratio of the engine, but this affects its power and efficiency, since the thermal efficiency of the Otto cycle is

$$\eta = 1 - \frac{1}{\varepsilon^{k-1}},$$

where ε is the compression ratio;

k is the adiabatic exponent (a constant).

The knocking tendency of an engine strongly depends on the quality of the fuel, whose stability to knocking is characterized by the octane number. The larger this number, the greater the stability of the fuel to knocking.

Special additives called antiknock agents are added to gasolines to raise their octane numbers.

The most common antiknock agent is ethyl fluid with tetraethyllead (TEL). TEL is a highly toxic substance requiring careful handling. On entering an engine cylinder, TEL reacts with oxygen, forming lead compounds.

Recently, under the direction of Academician A. N. Nesmeyanov, a new antiknock agent less toxic than TEL has been developed - cyclopentaldienyltricarbonylmanganese (CTM). Its use in the production of automobile gasolines is promising. The addition of the manganese additive to gasolines also decreases the carbon monoxide content of the exhaust gases.

The conditions of fuel combustion in the cylinder promote the formation of carbon-hydrogen compounds of complex structure, some of which are carcinogenic, i.e., produce cancers. They are present in the gaseous or liquid state in the exhaust gases. If the composition of the gases includes soot, the carcinogenic substances deposit on its particles. It is in this form that they are most dangerous, since they can be retained in the human lungs.

The difference between diesel and carburetor engines is that in the former, only the clean air necessary for the combustion enters the cylinders and is then burned therein. The fuel is supplied separately by a nozzle as the piston approaches the upper extreme position. At that moment the air pressure in the cylinder is 30-35 kg/cm^2, and the temperature is 500-600°C. Under such conditions, the fuel ignites spontaneously and burns. Part of this process takes place while the volume undergoes little change (in the ideal case when $V = \text{const}$), and part at a nearly constant pressure. This is the so-called Sabatier cycle.

The process of fuel combustion in diesel engines is very complex. Processes of vaporization of fuel droplets and oxidation of their vapors, both partial and total, take place simultaneously in the cylinder. Afterburning of individual fuel droplets takes place during the expansion.

Diesel engines operate at $\alpha = 1.4-1.7$, and sometimes at $\alpha > 2$. The carbon monoxide content of the exhaust gases of a diesel engine is therefore slight. However, because of the imperfection of the process, carbon monoxide is present in the gases, its quantity amounting to tenths of one percent by volume. Aldehydes are present in the exhaust gases, since their formation is involved in the preparation of the mixture for ignition. Afterburning of the individual droplets during the exhaust, taking place at lower pressures and temperatures, leads to the formation of large amounts of carbon black, which causes the black color of the exhaust gases of diesel engines, particularly at large loads. Because of the large amount of oxygen and nitrogen in the gases, and the fact that the process takes place at high temperatures and pressures, the conditions for the formation of nitrogen oxides in diesel engines are more favorable than in carburetor engines. They are also more favorable for the formation of sulfur dioxide, since the maximum sulfur content in diesel fuels specified by GOST 4749-49 and GOST 305-42 for all brands is limited to 0.2% by weight, and oxygen is present in excess. The conditions are also favor the formation of carcinogenic substances.

There are no lead compounds present in the exhaust gases of diesel engines since the additives used in diesel fuels contain no lead.

2. Composition of Exhaust Gases

The exhaust gases of internal combustion engines have a large number of components. Studies made in the Soviet Union have shown that the gases contain over 60 different substances. The composition of the gases includes:

Nitrogen (N_2) as the main part of the exhaust gases;
Oxygen (O_2);
Carbon dioxide (CO_2), an end product of oxidation;
Water vapor (H_2O), an end product of oxidation;
Hydrogen (H_2);
Carbon monoxide (CO), a product of incomplete fuel combustion;
Nitrogen oxides, present mainly in the form of two oxides: nitric oxide (NO) and nitrogen dioxide (NO_2);
Sulfur dioxide (SO_2) and hydrogen sulfied (H_2S), inorganic gases present in exhaust gases when sulfur fuels are used;
Oxygen-containing organic compounds, chiefly aldehydes: formaldehyde (HCHO), acrolein (CH_2-CH-CHO), acetaldehyde (CH_3CHO), etc;
Hydrocarbons: ethane (C_2H_6), methane (CH_4), ethylene (CH_2-CH_2), benzene (C_6H_6), propane (C_3H_8), acetylene (CH-CH), toluene ($C_6H_5CH_3$), m-xylene ($C_6H_4(CH_3)_2$), n-butane (C_4H_{10}), n-nonane (C_9H_{20}), etc;
Lead (Pb) or manganese (mn) and their compounds if antiknock additives are used;
Complex aromatic hydrocarbons of polycyclic structure (pyrene, anthracene, benzpyrene, etc.);
Soot.

These substances are present in the exhausts in the gaseous, liquid and solid states.

NOT REPRODUCIBLE

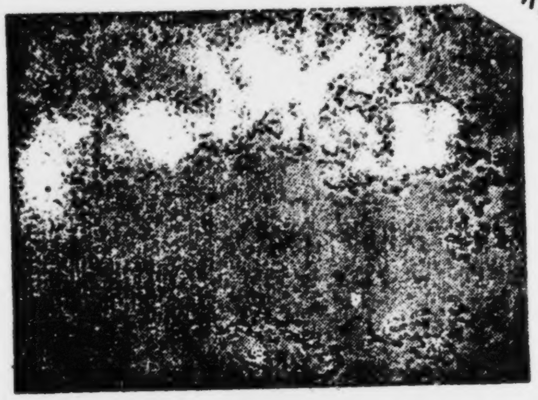

Fig. 1. Soot taken from exhaust gases of YaAZ-204 engine.

Soot should be considered separately. When the soot content in 1 m^3 of exhaust gases is 130 mg, they become visible, and when its content is 600 mg per m^3, they turn a medium black. Studies have shown that the majority of soot particles filtered out of black smoke (87-98%), are in the 0.04-0.50 μm range. They in turn consist of finer particles measuring 0.015-0.170 μm. The particles are round and oval in shape, Individual particles combine into groups consisting of two, ten, and more particles, and sometimes forming chains of up to 30 particles, or collect into aggregates of 100-1000 particles.

In accordance with the results of studies conducted at the Central Scientific Research and Experimental Design Laboratory for Exhaust Purification and Problems of Automobile and Tractor Power Engineering (LANE), Fig. 1 shows a sample of soot retained in an exhaust pipe. The photograph was made with an electron microscope at a total magnification of 35,000. The size distribution of the soot particles is shown in Fig. 2. The specific surface of all the soot particles ranges up to 75 m^2 per g. Since the visible exhaust gases correspond to a soot content of 130 mg per m^3 of gas, it means that the same volume has a surface area of up to 10 m^2 on which carcinogenic substances can deposit, and that there is an area of up to 45 m^2 for exhaust gases of medium blackness. Therefore, automobile soot is dangerous not only as a mechanical contaminant for human lungs, but also as an active carrier of carcinogens.

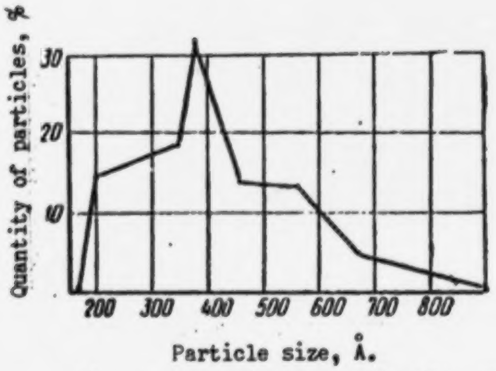

Fig. 2. Graphic of distribution of soot particles present in exhaust gases of YaAZ-204 engine as a function of size.

A tentative quantitative composition of exhaust gases is given in Table 2.

Table 2

Components	Gas Composition, % by Volume		Remark
	Carburetor Engines	Diesel Engines	
Nitrogen	74—77	76—78	Nontoxic
Oxyten	0,3—8,0	2—18	•
Water Vapor	3,0—5,5	0,5 — 4,0	•
Carbon Dioxide	5,0—12,0	1,0 —10,0	•
Carbon Monoxide	5,0—10,0	0,01— 0,50	Toxic
Nitrogen Oxide	0,0—0,8	0,0002—0,5000	•
Hydrocarbons	0,2—3,0	0,009—0,500	•
Aldehydes	0,0—0,2	0,001—0,009	•
Soot	0,0—0,04 g/m^3	0,01—1,10 g/m^3	•
Benzpyrene	up to10—20 $\gamma/м^3$	up to 10 $\gamma/м^3$	Carcinogenic

Note. γ (gamma) is one millionth of a gram.

The above table is not sufficiently representative, since the composition of the gases substantially depends on the type of fuel used, its additives, operating conditions of the engine, its technical condition, conditions of motion of the automobile, and other factors. Fig. 3 shows the relative dependence of the components of exhaust gases from a carburetor engine as a function of the load, and Fig. 4 as a function of the motion of the "Moskvich-408" automobile traveling over a hard-surface level road. It is obvious from the figures that the content of the individual componenets may change severalfold. For example, when the "Moskvich-408" travels at 70 km/hr, the exhaust gases of its engine contain 0.2-0.3% carbon monoxide. At a traveling speed of 120 km/hr, this value increases to 6%, and when the engine is idling, it rises to 7%.

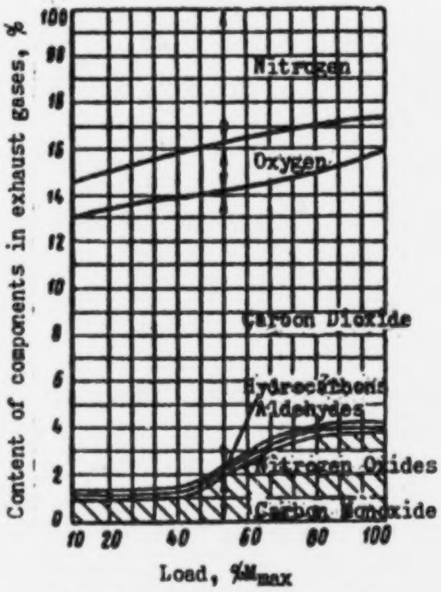

Fig. 3. Changes of the Interrelationship of the components of exhaust gases from a carburetor engine vs. load.

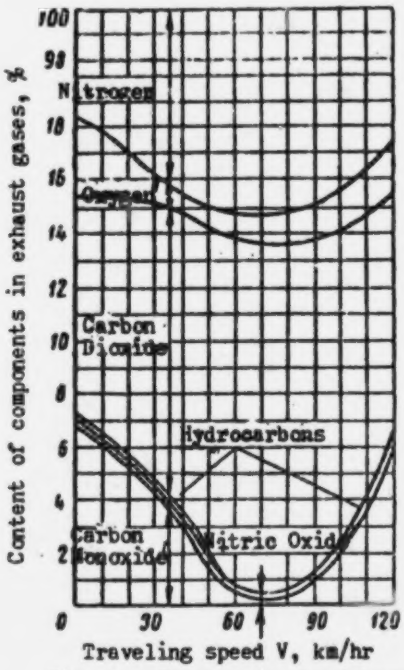

Fig. 4. Changes in the interrelationship of the components of exhaust gases from engine of "Moskvich-408" automobile vs. traveling speed.

Particularly undesirable are forced idling conditions.

A case of this type occurs during engine braking. The amount of carbon monoxide in the exhaust gases during the engine's operation under such conditions increases sharply, reaching 12% by volume in some cases. For example, the ZIL 130 engine may discharge up to 40-45 kg of CO per hour in this case.*

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* At a speed of 50-53 km/hr, the discharge of carbon monoxide into the atmosphere from a ZIL-130 engine amounts to about 1.5 kg/hr, and an increase of the velocity to 70 km/hr or decrease to 30 km/hr raises the discharge by a factor of approximately 2.5.

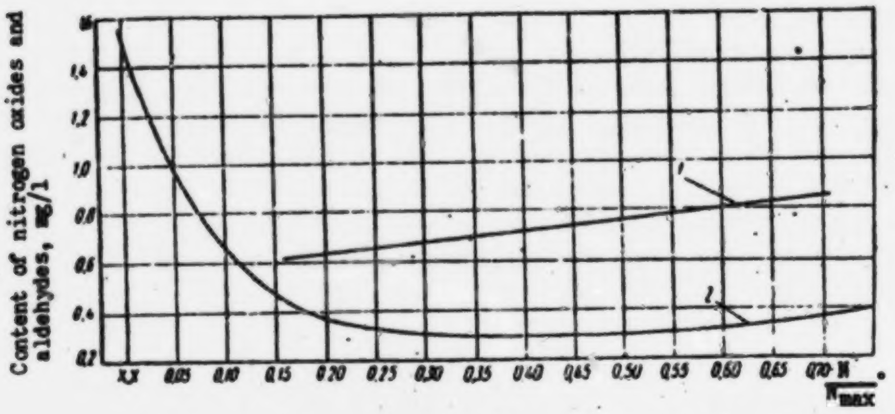

Fig. 5. Content of nitrogen oxides and aldehydes in the exhaust gases of YaAZ-204V engine:

1 - nitrogen oxides; 2 - aldehydes.

In diesel engines, the composition of exhaust gases also strongly depends on the operating conditions. It is well known that the black color of exhaust gases, characterized by a high soot content, is observed in diesel engines operating at a large load. Even in four-stroke diesel engines in good technical condition, the soot content of the exhaust gases may reach 1.1 g/m^3; in the old two-stroke diesel engines, this figure increases to 2.5 2.5 g/m^3. The content of nitrogen oxides in the exhaust gases also increases with the load. The content of aldehydes is minimum at a load of 40-50% N_{max}, increases on passing to operating conditions at small as well as large loads (Fig. 5), and rises very sharply in idle running.

3. Effect of the Main Components of Exhaust Gases on the Human Organism

Carbon monoxide. Under ordinary conditions, carbon monoxide is a gas without odor or color. It is lighter than air, and easily spreads through the atmosphere. Under the influence of carbon monoxide, red blood cells (erythrocytes) lose their ability to participate in the gas exchange vital to the human organism. Oxygen starvation sets in which primarily affects the central nervous system.

In acute carbon monoxide poisoning, man experiences extreme weakness, tinnitus, dizziness, headaches, precardial pain, nausea, and sometimes vomiting. He loses contact with the surroundings; some people become drowsy, others excited. Sometimes there are convulsions and frequently the victim loses consciousness.

In amounts above 0.01% by volume, carbon monoxide can cause symptoms of poisoning, and when it is present in the atmosphere in the amount of 0.02%, its inhalation for several hours may cause a light poisoning. Inhalation of air containing 0.12% CO in the course of 30 min causes a weak heartbeat, dizziness, after 1.5 hr, and headache, nausea and partial loss of consciousness after 2 hr. A 0.20-0.25% carbon monoxide concentration in air causes fainting after 30 min.

Nitrogen oxides. Engine exhausts contain two kinds of nitrogen oxides; nitric oxide (NO), a colorless gas, and nitrogen dioxide (NO_2), a reddish-brown gas with a characteristic odor. When they enter the human body, they combine with water, forming compounds of nitric and nitrous acids in the respiratory tract. Poisoning with nitrogen oxides is characterized by the presence of a latent period: a person who feels normal during work with dangerous concentrations of nitrogen oxide becomes seriously ill later.

The inhalation of 0.01% nitrogen oxides with air for 0.5-1.0 hr may cause a serious illness.

In their effect on the human organism, nitrogen oxides are approximately 10 times as dangerous as carbon monoxide.

Nitrogen oxides are irritating to the mucous membranes of the eyes, nose and mouth.

In addition, nitrogen oxides participate in processes leading to the formation of smog.

Usually, for convenience of comparison of nitrogen oxide contents, both gases are treated in toto with conversion to N_2O_5 according to the number of nitrogen atoms.

Aldehydes are present in the exhaust gases mainly in the form of formaldehyde and acrolein. Under ordinary conditions, formaldehyde is a gas with a pungent and unpleasant odor. On cooling, it condenses to a liquid boiling at -21°C; it irritates all the mucous membranes and injures the central nervous system. Both acute and chronic poisoning with gaseous formaldehyde causes inflammation of the respiratory organs.

When formaldehyde is present in the atmosphere in a concentration of 0.007%, a light irritation of the respiratory tract and mucous membranes of the eyes and nose is observed, and at a concentration of 0.18%, a marked irritation takes place. Formaldehyde is detected by its pungent odor when present in air in the amount of 0.0002 mg/l.

Acrolein is a gas (a liquid at temperatures below 52.5°C.) with the pungent, irritating odor of burned fats and oils. It is very poisonous. Its vapor is heavier than air. It has a strong irritating effect on the mucous membranes, and a general toxic effect. A content of 0.002% acrolein in the atmosphere is intolerable, 0.0003% is difficult to tolerate, and 0.00008 is not dangerous for man.

Carbon dioxide. This gas is without color or odor. It is heavier than air and collects in low areas. A high content of carbon dioxide in the atmosphere causes rapid breathing in man. It becomes dangerous to life only at concentrations of 20-25% by volume.

In areas where the accumulation of such high local concentrations of carbon dioxide in the atmosphere is not likely (open spaces), carbon dioxide should not be classified as a toxic gas.

Sulfur dioxide and hydrogen sulfide have a strong irritating effect on the mucous membrane of the eyes and olfactory organs, destroy plants, and participate in the formation of smogs.

Hydrocarbons. Although the hydrocarbons themselves are toxic, under the influence of sunlight they enter into further reactions with nitrogen oxides, forming ozone and peroxides. The latter cause irritation of the eyes, throat, and nose, and destroy plants.

Carcinogens. Among the carcinogens present in exhaust gases are benz(o)-pyrene and many others. Benz(o)pyrene is particularly dangerous.

Studies show that the formation of a malignant tumor requires direct contact between the carcinogen and live tissues, and the tumor appears, as a rule, at the site of this contact.

Direct contact can be achieved in practice by smearing various parts of the body with the carcinogen or by injecting it internally. For this reason, it was believed for a long time that the inhalation of carcinogenic substances did not cause lung cancer. Later, however, it was found that when carcinogens deposited on powder particles enter the lungs, they are given the opportunity to be retained in the body and to come in contact with its tissues. In the exhaust gases, the carcinogen carriers may be soot particles. Once a carcinogen enters the human body, it remains there for the rest of the individual's life. Its accumulation up to dangerous concentrations takes place gradually. This is one of the reasons why despite a general rise in the standard of living of all mankind and a lengthening of the average human lifespan, the vigorous development of industry and motor transport in particular have resulted in an increase of the death rate from lung cancer. In England, for example, during the period 1900-1952, the cancer death rate increased 43-fold. The content of carcinogenic substances in air has no sanitary norms and should have none. These substances should not be present in air altogether, and it is therefore necessary to limit their discharges.

Soot, like any other foreign dust, contaminates the respiratory tract, irritates it, and may cause chronic affections of the nasopharynx. On reaching the lungs, it also causes pulmonary diseases. However, the chief danger of soot is that it may carry carcinogens.

Lead compounds, which are present in exhaust gases when fluid with TEL is used, constitute poisons for all the organs and tissues of the body. They have a particularly adverse effect on the organism of children. Even a slight poisoning causes a retarded physical development, growth, and weight gain; nervous diseases appear, and the amount of hemoglobin and erythrocytes in the blood decreases.

The danger of poisoning with lead compounds is increased by the fact that as time passes, lead does not escape from the body but, like the carcinogens, accumulates up to dangerous concentrations. Lead compounds can enter the body through the respiratory organs as well as through the skin. As a result, the use of ethyl gasoline has been prohibited in a number of cities of the USSR.

The hydrocarbon fuels themselves are also toxic, particularly gasolines, or more accurately, their vapors. The degree of toxicity of gasoline vapors may be estimated from the following data: the maximum permissible mean daily concentration of carbon monoxide in air is 1 mg/m^3, and that of gasoline vapor, 1.5 mg/m^3.

4. Evaluation of the Toxicity of Exhaust Gases

It is clear from the preceding section that each toxic componenet of exhaust gases affects the human organism in different ways. The problem is to evaluate which are worse: the exhaust gases of carburetor engines or those of diesel engines, idling conditions or maximum loads, the use of ethyl fluid with TEL or CTM as antiknock additives, etc., when one considers that in each specific case the gases contain different amounts of individual substances.

Frequently in evaluating the harmful action of engine exhausts, use is made of figures showing the content of one or another toxic component. However, this is fundamentally incorrect. Thus, for example, one finds that the small amount of exhausts from the GAZ-20 engine at a rotational speed of the crankshaft of 1600 rpm, developing a power of 1 hp and containing 3% carbon monoxide by volume in the exhaust gases, contaminates atmospheric air to the same extent as the several-times larger volume of exhaust gases of the "Moskvich-401" automobile engine, which develops a power of up to 14 hp and whose composition of the exhaust gases contains carbon monoxide in the same concentration of 3%. The contamination of air with engine exhausts should not be evaluated from the percent composition of toxic components in the exhaust gases but from the total amount of the discharged components, taking into account the degree of harmful action of each. In order to take into consideration the operating conditions of the engine as well, this quantity should be expressed per unit of power developed by the engine.

Since 1962, at the Central Scientific Research and Experimental Design Laboratory of Exhaust Purification and Problems of Automobile and Tractor Power Engineering (LANE) in evaluating the harmful action of the operation of a specific engine for given operating conditions, a parameter expressing the specific toxicity of exhaust gases has been used which is represented by the expression

$$q_e=\sum_i \frac{\nu_{co}}{\nu_i}\frac{G_i}{N_e},$$

where G_i is the discharge of the given toxic substance "i" from the engine per unit time;

N_e is the effective power developed by the engine;

ν_{CO}, ν_i are sanitary norms of the maximum permissible contents of carbon monoxide and substance i in air.

The right side of this formula contains the sum of the amounts of all the noxious substances discharged by the engine during a given time interval and expressed per unit power, $\sum_i \frac{G_i}{N_e}$. In order to take into account the different toxicities of the substances, each of them is expressed in terms of the best-studied substance, carbon monoxide, by the ratio $\frac{\nu_{co}}{\nu_i}$, which shows how many times CO is more or less dangerous than substance i. Since the USSR has adopted sanitary norms which ensure complete safety to man in a contaminated atmosphere, standardization using the proposed parameter is the answer to the problem of evaluating an engine from the standpoint of the toxicity of its exhaust gases.

The magnitude of the specific toxicity of exhaust gases makes it possible to evaluate the degree of harmful action of the exhausts of any engine operating under any conditions except idling. In the latter case, $N_e=0$, and according to the formula given above, q_e loses meaning. Therefore, in estimating the degree of toxicity of engine exhausts in the case of idling, a special conventional quantity called the conventional specific toxicity of idling is introduced. It differs from the specific toxicity of engine exhausts in that it does not refer to the power developed by the engine, but to the maximum power that the given engine can develop. The mathematical formula for its determination is

$$q_{x.x}=\sum_i \frac{\nu_{co}}{\nu_i}\,\frac{G_i}{N_{max}}.$$

It now becomes possible to evaluate the degree of general contamination of atmospheric air with the exhaust gases of any engine operating under any conditions.

Let us assume, for example, that a carburetor engine devloping a power of 20 hp discharges the following composition of exhaust gases in the course of an hour: 30 g of carbon monoxide, 0.9 g of aldehydes, 2.5 g of hydrocarbons and 0.9 g of nitrogen oxides. Then, taking the following approved sanitary norms: for CO $\nu_{CO} = 1$ mg/m^3, for aldehydes $\nu_{ald} = 0.1$ mg/m^3, for hydrocarbons $\nu_{hyd} = 2$ mg/m^3, for nitrogen oxides $\nu_{niox} = 0.1$ mg/m^3, in the case of an engine operating under certain given conditions, we have the following values of the specific toxicity of the exhaust gases:

$$q_e = \frac{1.0 \times 30}{1.0 \times 20} + \frac{1.0 \times 0.9}{0.1 \times 20} + \frac{1.0 \times 2.5}{2.0 \times 20} + \frac{1.0 \times 0.9}{0.1 \times 20} = 2.4625 \text{ g/hp hr}$$

The concept of specific toxicity of exhaust gases permits not only an evaluation of the engine from the standpoint of contamination of the atmosphere, but also the determination of the fraction which each toxic component "contributes" to the overall toxicity of the gases of a specific engine.

Indeed, if in the example under consideration $q_e = 2.4625$ g/hp hr and the specific toxicity of the exhaust gases for carbon monoxide alone is

$$q_{e_{co}}=\frac{1,0}{1,0}\cdot\frac{30}{20}=1,5 \text{ g/hp hr},$$

this means that the carbon monoxide fraction in the overal toxicity is correspondingly equal to

$$\omega_{co}=\frac{q_{e_{co}}}{q_e}\cdot 100=\frac{1,5}{2,4625}\cdot 100\approx 61\%.$$

Fig. 6 shows a graph of the distribution of toxicity of carburetor engine exhausts according to componenets as a function of the excess air coefficient α , plotted by using the above method. It is evident from the graph that for rich mixtures, the main toxic component is CO, whose fraction in the overall toxicity at $\alpha = 0.85$ is as high as 95%. For lean mixtures, where no deficiency of oxygen occurs during the combustion, and the conditions are unfavorable for the formation of carbon monoxide, the chief toxic components are nitrogen oxides.

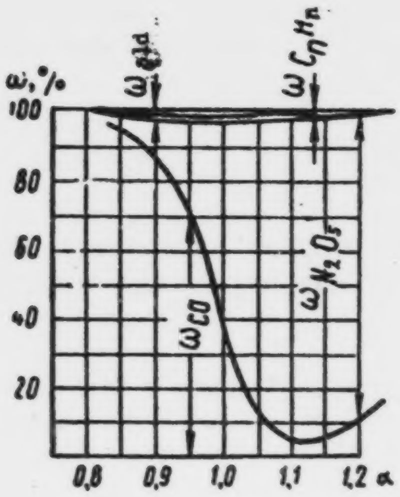

Fig. 6.
Toxicity ω of engine exhausts versus excess air coefficient α

The indicated graph permits the following practical conclusion. If the engine is adjusted for a rich mixture, then in developing ways of decreasing the total toxicity of exhaust gases it is necessary first of all to direct one's attention to the neutralization of carbon monoxide. In operation on lean mixtures, the main emphasis should be on reducing the concentration of nitrogen oxides.

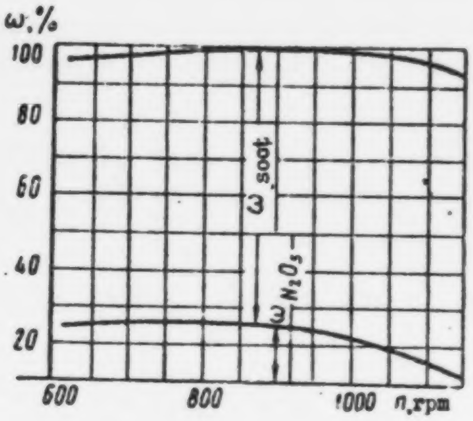

Fig. 7.
Toxicity ω of diesel engine exhausts versus number of revolutions of crankshaft.

In diesel engines the situation is different. This is evident from Fig. 7 and 8, which show the distributions of the toxicity of diesel engine exhausts over the components as a function of the rotational speed of the crankshaft (Fig. 7) and load (Fig. 8). * In operation with a high-speed external characteristic (see Fig. 7), the main part in the toxicity is played by soot (75-85%). The relationship changes with the load: the fraction of nitrogen oxides accounts for 55-70% of the overall toxicity, and the soot becomes secondary, although its toxicity continues to account for 30-40%. In both cases, the fraction of carbon monoxide in the overall toxicity is slight, as is that of the other noxious substances.

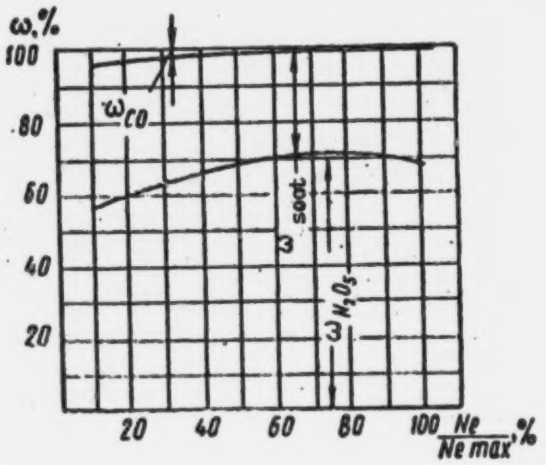

Fig. 8. Toxicity ω of diesel engine exhaust vs. load.

It follows that in neutralizing the exhausts of diesel engines, it is necessary to control primarily the soot and nitrogen oxides.

The indicated graphs do not show carcinogens or lead compounds. Since carcinogens and lead compounds are not eliminated from the human body, accumulating in the latter up to dangerous concentrations, their presence in any, even slight, concentrations is dangerous for man.

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* The graphs were plotted under the assumption that the entire mass of the soot discharged remains in the air for a long time.

It should be noted that Soviet laws have prohibited the use of ethyl fluid with TEL as an antiknock additive in the country's large cities.

The specific toxicity parameters permit an objective evaluation of the quality of engines from the standpoint of their contamination of the atmosphere both for engines being operated and those having undergone repair, and even for new ones being finished in plants.

Chapter II

CONTROL OF EXHAUST GASES

1. Analysis of Exhaust Gases

Complete chemical analysis of the composition of gas and air samples for their content of certain components is carried out in specialized laboratories. The analysis is preceded by the collection of gas samples. The samples are collected in special containers whose type is determined by the purpose of the analysis. The gas may be passed for a certain period of time through absorbing instruments in which the substance being determined is trapped, or it may be caught in gas collectors (aspirators). To enable the gas to reach the gas collectors independently, the air in the latter is partly evacuated, i. e., a vacuum of 10-15 mm Hg is produced. Occasionally, the gas collectors used are rubber balloons that are filled with the gas by means of squeeze bulbs.

For each specific case, a special health and sanitation commission has recommended conditions of sampling for the determination of the highest single and mean daily permissible concentrations. In the study of the toxicity of automobile exhausts, in order to avoid their dilution by atmospheric air, the samples are collected directly from the exhaust pipes of the engines.

The samples sent to the laboratory are analyzed. The most diverse methods of analytical chemistry and corresponding instruments are used in the analysis.

The simplest and yet adequately sensitive is the colorimetric method.

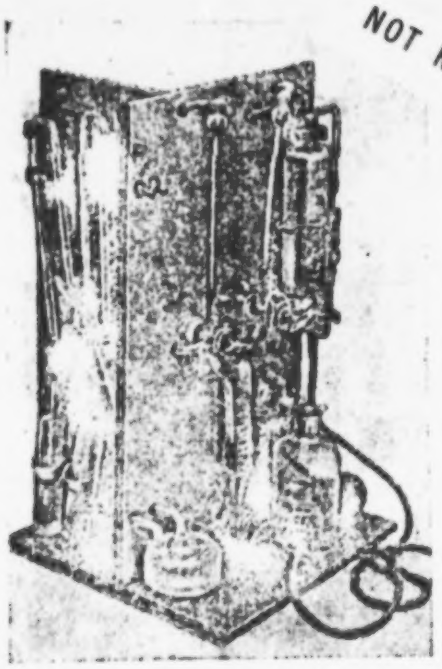
The method is based on the ability of solutions of certain substances to acquire a color when acted upon by chemical reagents. The color intensity of the solution increases in proportion to the amount of substance it contains. In order to determine the amount of the substance studied from the color of the solution, the intensity of this color is compared with that of the solution containing a known concentration of the same substance.

For example, in the determination of formaldehyde in a gas, it is first dissolved in water (by pouring water into the flask containing the gas), a part of the solution is poured into a test tube, fuchsin sulfurous acid (Schiff's reagent) is added, and the solution is agitated and allowed to stand for 1 hr. A small amount of sulfuric acid is then added to the test tube, and the solution turns blue. This color of the sample is compared with a standard scale consisting of seven samples containing solutions with known amounts of formaldehyde.

Despite what might at first glance be thought to be the inaccuracy of this method, its sensitivity is sufficiently high. For formaldehyde, it amounts to 1 γ in a volume of 5 ml of solution; for acrolein, 0.002 mg in a volume of 2 ml; and for nitrogen oxides, 0.05 γ in a volume of 3.5 ml.

Since the accuracy of the method depends to some extent on the eye of the laboratory technician, i. e., his ability to compare correctly the color intensities, the photocolorimetric method has recently begun to be employed. It differs from the above-described technique in that light whose intensity is recorded with a photoelectric cell is passed through the test tubes containing the samples. The concentration of the substance studied is determined from the magnitude of the photocurrent. This method is undeniably more accurate and faster, but it also has disadvantages. For example, at very low concentrations and hence, weak intensities, the photoelectric cell reacts weakly to the color change.

The carbon monoxide content of the gases under laboratory conditions is determined by means of gas analyzers. The TG-5 instrument (Fig. 9) is very common in the analysis of gases with a low CO content. This gas analyzer consists of two parts: purification and analysis. In the purification part, foreign impurities are removed from the gas. In the analysis part, carbon monoxide is burned in a special column on an incandescent platinum spiral. The amount of carbon dioxide formed by the combustion of CO is then determined chemically, and from the amount obtained, the carbon monoxide content of the initial sample is calculated. The sensitivity of the gas analyzer ranges from 0.0014 mg to 0.0028 mg. Operation of the instrument requires a certain experience and qualifications on the part of the laboratory technician.



NOT REPRODUCIBLE

Fig. 9. The TG-5 Gas Analyzer.

If carbon monoxide is present in the gaseous mixture in concentrations amounting to a few percent by volume, GOST 5439-56 recommends an instrument of model VTI-2 for the determination of the CO content. In addition to carbon monoxide, analysis with this instrument permits the determination in the gaseous mixture of individual concentrations of oxygen, nitrogen, methane, total concentrations of carbon dioxide, sulfur dioxide, hydrogen sulfide and other acid gases, and also unsaturated hydrocarbons (C_nH_m) and hydrogen plus saturated hydrocarbons (C_nH_{2m+2}).

The principle of operation of the instrument is based on a selective absorption of individual components of the gases by liquid substances. A given volume of gas is pumped through a liquid absorber, and an individual component of the gas is absorbed.

The content of this component in the mixture is determined from the change in the volume of the gas.

In the determination of the hydrogen content plus saturated hydrocarbons and methane, the gas is additionally burned over copper oxide.

The accuracy of the instrument in the determination by the absorption method (analysis for the content of acid gases, C_nH_m, O_2) is 0.2%, and in the analysis by the combustion method (for the content of H_2, C_nH_{2m+2}, methane CH_4), 0.3%.

Operation of the instrument requires certain qualifications on the part of the laboratory technician.

Recently, automatic and semiautomatic recording instruments for gas analysis have appeared in laboratory practice. They include primarily chromatographs and optico-acoustic gas analyzers. Some instruments include electronic parts. In practice, they have thus far been used mostly in specialized laboratories.

Analysis of gas samples for the content of soot and various solids is carried out in the following manner. A given volume of gas is passed through a filter made of paper or a special material packed in a cartridge. A perfect filter of brand BF, also called the Petryanov filter, is frequently used. At high temperatures of the exhaust gases, the filter material used may also be high-temperature ultrafine fiberglass. The solid particles are trapped on the filter.

The filter material darkens. The degree of darkening of the filter is compared with a standard scale, from which the solid particle content of the gas is determined. This method is called the Bosch method.

The components held on the filter material can be removed by chemical means. Analysis then gives an accurate content of the studied substance present in the gas. In particular, this method is used to determine the content of carcinogens present in the liquid and solid states in the exhaust gases.

A second method of indirect determination of the content of solid particles in a gas is the Hartridge method. This method is used to determine the smoke content of exhaust gases. It essentially consists of shining light through a definite volume of gas. Part of the light flux will of course be blocked by the particles suspended in the gas and will not reach the recording cell. From the difference between the emitted light flux and the flux recorded by the instrument one can determine the smoke content of the exhaust gases and indirectly the content of particles suspended in the gas.

Fig. 10 gives a comparison of the Bosch and Hartridge units. Since the Bosch instruments measure the actual amount of particles suspended in the gas, and the Hartridge instruments the optical density of a given volume of aerosol, this density being only partly dependent on the dispersed phase, a considerable scatter is observed on passing from one set of units to the other. This accounts for the replacement of a curve by an area in the lower part of the figure.

For carburetor engines, the necessity of standardizing the content of carbon monoxide in exhaust gases has been universally recognized. Standardization of hydrocarbon emission has been adopted in the U.S.A., where limitations on nitrogen oxides are also being proposed.

In Europe, the emission of hydrocarbons is determined as a checking figure supplementary to the data on CO.

For diesel engines, norms for the soot content of exhaust gases have been the only ones introduced thus far.

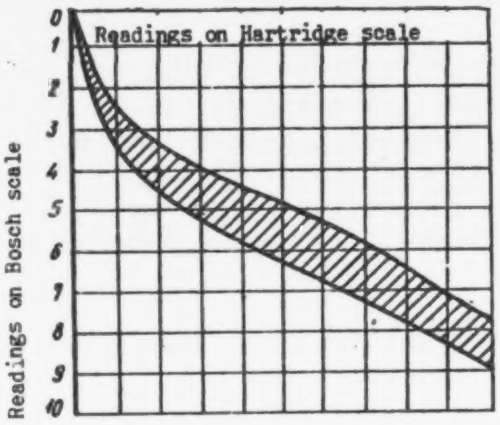


Fig. 10. Comparison of readings of the Bosch and Hartridge scales.

The standardization is based on the so-called "driving cycle." The automobile is operated sucessively in all the runs specified by the cycle. During the operation, samples of exhaust gas are collected and analyzed for the content of the components being standardized. Data of the analysis are averaged out, converted by means of special formulas, and a conclusion is reached concerning the quality of the automobile from the standpoint of the toxicity of its engine exhausts.

Driving cycles are worked out on the basis of studies of the conditions of traffic flow in cities.

Two types of driving cycles are distinguished, the American and the European. The American driving cycle (septuple repetition of 7-run cycle, total automobile testing time 15 min) is shown in Table 3, and the European driving cycle (quadruple repetition of a twenty-six-run cycle, total automobile testing time 13 min) is shown in Table 4.

For automobiles operated in cities of the USSR, LANE has developed its own driving cycle which takes into consideration the characteristics of urban transport. This cycle is being extensively studies at the present time. Special driving cycles exist for automobiles used in open quarries, mines, tunnels, etc.

All the tests are carried out on special stands with revolving drums. In the USSR, the first such stand was built by LANE at the First Automobile Complex of the Main Moscow Administration of Motorized Transport.

Table 3

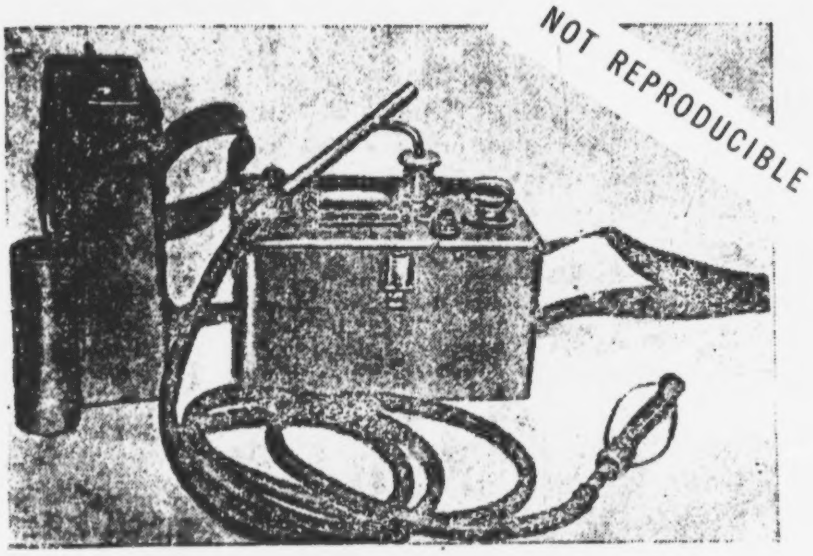
Run of Automobile	Speed, km/hr	Acceleration m/sec^2	Duration of run, sec	Accumulated time sec
Idling engine	—	—	20	20
Acceleration of Automobile	0—48	0,97	14	34
Constant Speed	48	—	15	49
Deceleration of Automobile	48 – 24	0,64	11	60
Constant Speed	24	—	15	75
Acceleration of Automobile	24—80	0,53	29	104
Deceleration of Automobile	80—0	0,9	25	129

Table 4

Automobile Run	Gear Used	Speed, km/hr	Acceleration, m/sec^2	Duration of run, sec	Accumulated time, sec
Idling	—	—	—	7	7
Acceleration of automobile	1	0—15	1,04	4	11
Constant speed	1	15	—	8	19
Deceleration of automobile	1	15—10	0,69	2	21
Deceleration with disengaged engine	—	10—0	0,92	3	24
Idling	—	—	—	21	45
Acceleration of automobile	1	0—15	0,83	5	50
Gear shifting	1—2	—	—	2	52
Acceleration of automobile	2	15—30	0,83	5	57
Constant speed	2	30	—	14	71
Deceleration of automobile	2	30—10	0,69	8	79
Deceleration with disengaged engine	—	10-0	0,92	3	82
Idling	—	—	—	21	103
Acceleration of automobile	1	0—15	0,83	5	108
Gear shifting	1—2	—	—	2	110
Acceleration of automobile	2	15—35	0,62	9	119
Constant speed	2	35	—	10	129
Gear shifting	2—3	—	—	2	131
Acceleration of automobile	3	35—50	0,52	8	139
Constant speed	3	50	—	12	151
Deceleration of automobile	3	50—35	0,52	8	159
Constant speed	3	35	—	13	172
Gear shifting	3—2	35	—	2	174
Deceleration of automobile	2	35—10	0,99	7	181
Deceleration with disengaged engine	—	10—0	0,92	3	184
Idling	—	—	—	11	195

2. Rapid Analysis of Exhaust Gases

In practice, a complete analysis of the composition of exhaust gases is performed only in testing new engines and special devices for neutralizing gases, and also when required by the staff of the sanitary inspection. Sometimes it is necessary to make a rapid check of the content of the main toxic components of a gas in order to get an idea of the adjustment of an engine and its technical condition. As was pointed out in §4 of Chapter I, such components are: carbon monoxide for carburetor engines, and soot for diesel engines. In the Soviet Union, portable instruments have been developed for such analyses. One such portable instrument is an I-SO indicator constructed by the Scientific Research Institute for Motor Transport for determining the permissible content of the total amount of carbon monoxide and hydrocarbons in automobile exhausts (Fig. 11).



NOT REPRODUCIBLE

Fig. 11. I-SO exhaust indicator.

The indicator can operate normally at ambient air temperatures of up to 40° C, and a relative humidity of up to 80%. It weighs 3.5 kg; the external dimensions are 206 x 85 x 128 mm. The concentration of toxic components is measured directly from the automobile.

The indicator can measure the concentration of carbon monoxide plus hydrocarbons in the range from 0 to 10% by volume. Its comparatively low sensitivity does not permit its use for the analysis of the composition of diesel engine exhausts, in which the content of carbon monoxide and hydrocarbons is relatively low.

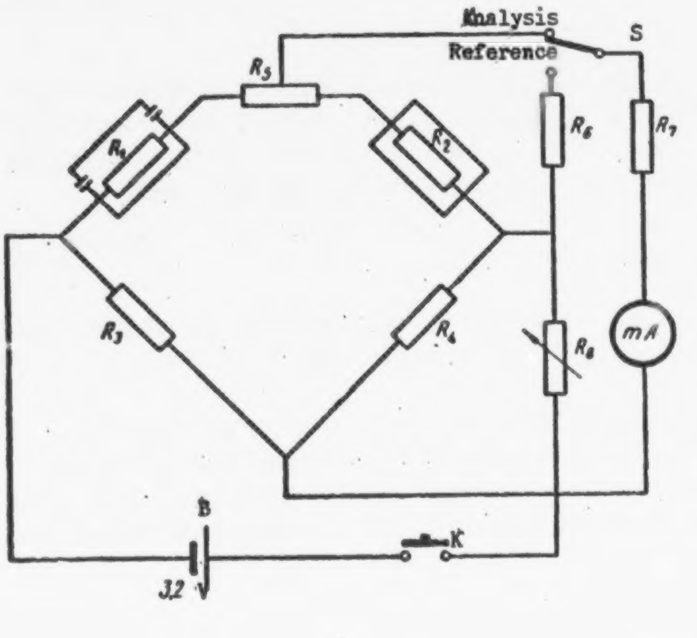


Fig. 12. Electric diagram of portable I-SO exhaust indicator.

The operation of the indicator is based on the measurement of the temperature elevation of a platinum wire preheated to 400° C, on the surface of which a catalytic combustion (i. e., accelerated by the platinum catalyst) of carbon monoxide and hydrocarbons takes place. The main part of the electric circuit of the instrument (Fig. 12) is an unbalanced direct current bridge to the two arms of which (R_1 and R_2) platinum elements are connected. One of the arms (R_1) is the working element and is placed in the chamber through which the exhaust gases are passing, and the second is the reference element (R_2) enclosed in an insulated chamber filled with air. When switch S is in the Reference position and key K is closed, rheostat R_8 establishes a current from the B-power supply (two flashlight batteries) such that the platinum wires heat up to 400° C.

Before the measurement, the instrument is balanced. Switch S is placed in the Analysis position, key K is closed, and rheostat R_5 is set so that the current is uniformly distributed between the resistances and does not pass through the milliammeter mA. If the exhaust gases are then passed through the chamber with platinum wire R_1, the carbon monoxide and hydrocarbons present in them will burn on the surface of the wire. The wire temperature will rise, resulting in an increase of the resistance of element R_1. At the same time, the current distribution will change, and part of it will flow through the milliammeter and cause the indicator of the instrument to deflect. The indicator scale has two zones: green, corresponding to the permissible content of carbon monoxide and hydrocarbons in the exhaust gases, i. e., 0-2% by volume, and red (2-10%), prohibiting the operation in a city of an engine with such toxic exhausts.

The automobile engine exhausts entering the instrument for analysis are drawn through it by means of a special piston pump. The samples are collected directly from the exhaust pipe of the automobile. Before entering the measuring chamber, the gases are purified by removing solid and liquid particles and are diluted with air.

The analysis of the exhaust gases should be carried out in a steady run of the engine. It then becomes necessary to watch the choke of the carburetor to make sure that it is fully open. The determination of the carbon monoxide and hydrocarbon contents is recommended for the following engine runs:
slow idle (up to 600 rpm);
fast idle (2200-2400 rpm).

To determine the permissible content of soot in automobile exhausts, portable indicators (soot meters) designed by LANE are employed.

The general appearance of one of the soot meters is shown in Fig. 13. The soot meter consists of two main parts: a corrugated bulb pump and a filter cartridge. Before starting the analysis, the instrument is prepared for operation. To this end, the shaft is pushed downward and the corrugated metallic bulb pump is compressed and left in this position by means of a catch.

An absolute filter of brand BF is loaded into the filter cartridge.

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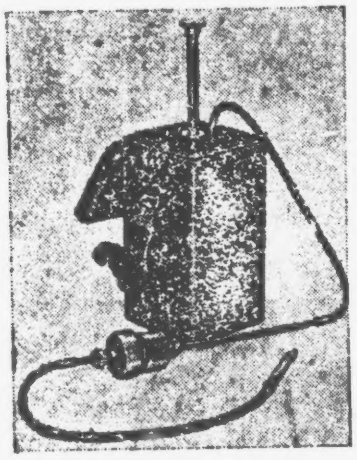

Fig. 13. Portable instrument of LANE design for determining the soot content of exhaust gases.

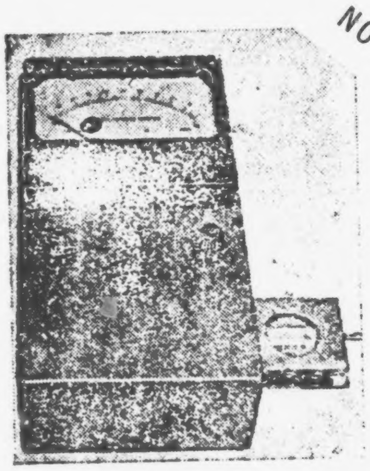

Fig. 14. Indicator instrument of LANE 35/300 soot meter.

The analysis consists in the following: the gas sampler is introduced into the exhaust pipe, and the catch is released. The bulb pump expands and draws 300 cm^3 of exhaust gas through the filter at a certain known rate. All the soot particles deposit on the filter surface, and the filter darkens.

The filter is removed from its cartridge, and the degree of darkening is compared with the standard scale.

The improved LANE 35/300 soot meter is also portable. It differs from the one discussed above in that the determination of the amount of soot deposited on the filter is made with the aid of a special instrument (Fig. 14). The instrument is connected to a photoelectric cell which relates the degree of darkening of the filter to the magnitude of the photocurrent recorded by the milliammeter. The scale of the instrument is calibrated in this case so that one can get a direct reading of the amount of soot contained in a cubic meter of exhaust gases. A description of the instrument and its comparison with the characteristics of the German instrument Bosch EFAW-78 are given in Table 5.

Table 5

Parameters	LANE 35/300 instrument	Bosch EFAW-78 Instrument
Accuracy class	1,5	2,0
Weight of set, kg	5,0	12,0
Volume of gas sample, cm^3	300	330
Working diameter of filter, cm	2,0	3,3
Time of collection of sample, sec	3,5	1,5
Filtering material	BF or FPA-15 cloth made of ultrafine cellulose acetate fibers	Filter Paper
Breakthrough coefficient for diesel soot, %	0,0	30,0
Allowable working temperature of filter, °C.	Up to 150	Up to 50

Chapter III

METHODS OF REDUCING THE FORMATION OF TOXIC COMPONENTS IN EXHAUST GASES

1. Operating Conditions of Engine

We shall discuss the toxicity of carburetor engine exhausts as a function of the conditions of operation by taking the ZIL-130 engine as an example. The dependence of the specific toxicity of exhaust gases on the engine load has the following values:

Engine load, % of maximum power ..	20	30	40	50	60	70	80	90	100
Specific toxicity, g/hp hr*	4.65	3.00	2.00	1.50	1.00	0.60	0.30	0.97	8.00

It is evident that the toxicity of the exhaust gases decreases with increasing load, reaching a minimum at 80% of maximum load, then increases sharply. This is because a rich mixture is supplied to the engine cylinders under full power conditions. As a result, the conditions of combustion worsen substantially, and the content of incomplete combustion products including carbon monoxide increases in the exhaust gases.

Thus, in order to ensure the minimum toxicity of engine exhausts in operating an automobile, it is necessary to try to stick to conditions corresponding to a 70-80% engine load and to avoid full power.

Unfortunately, in cities it is impossible to run an automobile under constant conditions, and to avoid full loads. The conditions change continually, and a considerable amount of time corresponds to light loads, idling, and forced idling conditions.

Studies carried out at the Engine Institute of the USSR Academy of Sciences by Candidate of Technical Sciences V. I. Bernatskiy for the purpose of determining the predominant operating conditions of the GAZ-21 "Volga" automobile under urban conditions showed that under load, the engine works only 57% of the total time. The remaining 43% include idling and forced idling, the latter amounting to over 16%. How does the operation of the engine under these conditions affect the air pollution?

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* Specific toxicity values calculated by considering carbon monoxide, nitrogen oxide, hydrocarbons and aldehydes at a crankshaft speed of 3000 rpm.

Graphs of the dependence of conventional specific toxicities of idling on the speed of rotation of the crankshaft for four engines are illustrated in Fig. 15: three domestic and one 8-cylinder American engine of the Imperial model, with a rated power of 250 hp at 4500 rpm (compression ratio 10, 11, V-type arrangement of cylinders). The figure shows that the emission of toxic substances during idling is considerable. It is noteworthy that a relatively "clean" engine is the domestic model GAZ-53, and the most unsafe is the American engine.

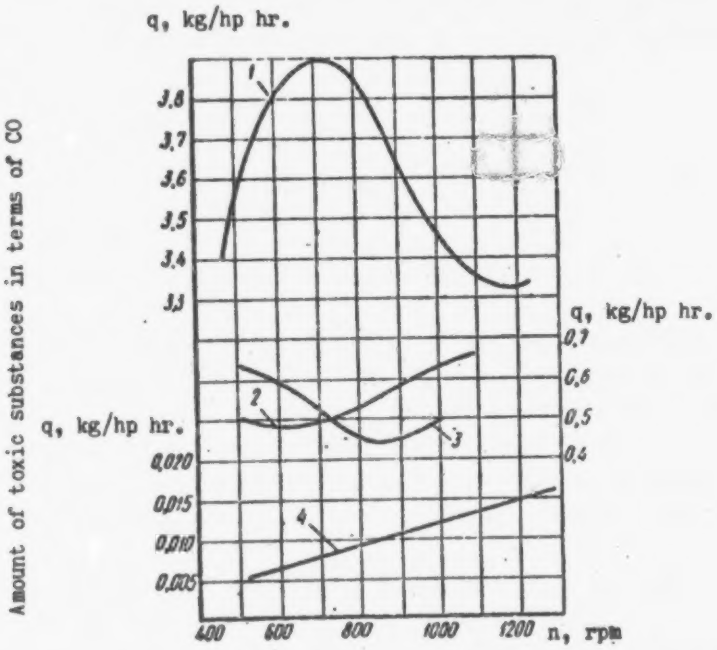


Fig. 15. Conventional specific toxicities for idling vs. rotational speed of crankshafts of the engines:
1 - Imperial; 2 - ZIL-130; 3 - ZIL-120; 4 - GAZ-53.

The above dependences do not permit one to determine which rotational speeds of the crankshaft are associated with the cleanest idling, since each engine has its own dependence with its own characteristics. It may be noted only that higher rotational speeds of the crankshaft, above 850-900 rpm, increase the noxiousness of the exhaust gases in all the domestic engines studied. Hence, if the engine is to run idle, the crankshaft speed should be kept low.

Forced idling is particularly undesirable for an engine. In this case the crankshaft rotates at a higher speed; the carburetor throttle, whose position corresponds to idling, is closed. A high vacuum is produced in the cylinders, and a rich mixture is supplied. This causes incomplete combustion and increased consumption of fuel. Moreover, oil seeps into the cylinders from the crankcase, and its combustion raises the toxicity of the exhaust gases and causes scaling. The spark plugs are splashed with oil and liquid fuel. As a result, spark failure is observed. Large amounts of fuel vapors which also are toxic enter the exhaust pipe and hence the atmosphere. For the GAZ-53 engine, the conventional specific toxicity under forced idling conditions can rise to as high as 1.2 g/hp hr, which surpasses the conventional specific toxicity associated with regular idling by a factor of six. In other words, from the standpoint of poisoning of atmospheric air with products of exhaust gases, forced idling is six times as dangerous as regular idling.

How can one reduce the time of operation of the engine under these adverse conditions? First of all, by organizing urban traffic so that frequent mandatory stopping of automobiles is eliminated. This is done, for example, by using underground pedestrian crossings, elevated roads, and tunnels, by introducing one-way traffic, by installing automatic traffic lights at intersections, and by other measures.

Diesel engines also have their own optimum operating conditions corresponding to the minimum toxicity of their exhaust gases: this corresponds to 60-70% of the maximum load. Full load is undesirable: the exhaust gases turn black and contain particles of soot, which is one of the main toxic components of the exhaust gases of a diesel engine. Rapidly changing engine loads, (i. e., during the so-called racing of the engine) are also unsafe.

2. Engine Adjustment

The power developed by an engine is basically determined by the amount of fuel supplied to the cylinders. For the same amount of fuel supplied, it is also possible to adjust the power of the engine over a certain range. In carburetor engines, this is done by altering the composition of the mixture (i. e., the excess air coefficient α) and the angle of ignition advance θ. In diesel engines, the power is adjusted by changing other parameters, in particular, the angle of injection advance θ and the injection time τ_{inj}. We shall discuss the essential features of these adjustments in more detail.

In carburetor engines, for a given fuel feed, the power is primarily determined by the fuel combustion rate. As already indicated in §1 of Chapter 1, the highest combustion rate is achieved in this case when α=0.85-0.90. Deviation from this value in the direction of both lean and rich mixtures results in a decrease of engine power. The indicated fuel ratio is not optimal from all points of view. First of all, far from the total heat-generating capacity of the fuel is utilized here, since the combustion of its major portion does not reach completion (for $\alpha < 1$). The efficiency of the engine is relatively low. Tests show that the most complete utilization of the energy contained in the fuel takes place when α= 1.05-1.15. The dependence of the effective performance indices of a carburetor engine (power and specific fuel consumption) on the excess air coefficient shows (Fig. 16) that for a given portion of air supplied to the cylinders, there are two optimum values of α: one provides for the development of maximum power by the engine, and the other ensures the best economy of its operation. In order to decrease the fuel consumption, the engine is usually adjusted for the economical mixture, and a power adjustment is resorted to only when necessary. This is accomplished by selecting appropriate carburetor jet tubes or by periodically connecting special carburetor attachments.

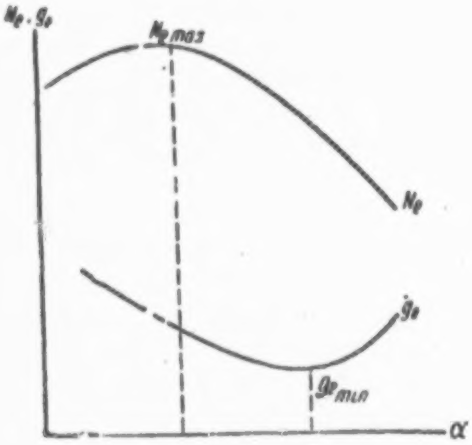


Fig. 16. Effective power and specific fuel consumption of a carburetor engine vs. mixture ratio.

All the operating conditions of an engine can be divided into three groups: idling and small loads; range of medium load; maximum loading and close to maximum loads.

In the range of idling and small loads, the throttle is not more than 25% open. Little fuel and air reach the cylinders. In addition, the working mixture is highly diluted with gases left over from the preceding cycle. The ignition of such a mixture is considerably hindered, and its combustion rate is slow. If in this case an economical mixture is supplied to the cylinders, the operation of the engine will be unstable with standard ignition systems; even misfiring is possible. It is therefore necessary to adjust the engine for a somewhat richer mixture than the economical mixture. This is accomplished by means of the idling system of the carburetor.

At medium loads (with the throttle 25-85% open) there are no obstacles to the adjustment of the engine for an economical mixture.

The engine operates stably at all rotational speeds of the crankshaft and at a mixture ratio corresponding to α = 1.05-1.15.

When the engine operates at large loads, the question of economy becomes secondary. It becomes most important to obtain the maximum power from the engine. For operation under these conditions, the engine is adjusted for a power mixture. This is achieved by connecting an economizer, which supplies an additional amount of fuel.

An enriched mixture is supplied not only when the engine operates under close to maximum loads. To improve the dynamics of the automobile when the accelerator pedal is abruptly depressed, the mixture is also enriched by the acceleration pump, but only for a short time.

In order to approximate the ideal Otto cycle and to increase the engine power, the mixture is not ignited when the piston is located in the extreme upper position, but slightly earlier. Tests have shown that for various reasons, particularly because the moving piston may produce a vigorous mixing of the fuel-air charge, the maximum combustion rate is observed at angles of ignition advance of 20-40°.

It is natural at this point to ask the question, does a change of these parameters (excess air coefficient and angle of ignition advance) have an effect on the toxicity of the exhaust gases of a carburetor engine, and if so, to what extent?

In order to answer this question, tests were set up at LANE using a single-cylinder engine to study the effect of changing the adjustment parameters on the content of individual noxious substances in the exhaust gases. The compression ratio of the engine was $\varepsilon=8$, the number of revolutions $n = 1500$ rpm, and the excess air coefficient $\alpha=1.27$. The experiments showed that as the angle of ignition advance changes, the concentrations of carbon monoxide and nitrogen oxides remain unchanged. This pattern was also confirmed for other values of the compression ratio ($\varepsilon=7$; 9; 10) and excess air coefficient ($\alpha=0.94$; 1.17; 1.25). Hence it was concluded that, to a first approximation, the concentrations of the principal toxic substances and hence the toxicity of the engine exhausts are independent of the angle of ignition advance. Therefore, in the daily operation of carburetor engines, the optimum angle of ignition advance should be set only so as to obtain the maximum power and economy, without consideration of the toxicity of the exhaust gases.

If, however, we consider the effect of the excess air coefficient on the content of toxic components in the exhaust gases, the picture changes completely. The curve representing the dependence of the carbon monoxide content in the exhausts of the GAZ-51 engine on the excess air coefficient (Fig. 17) at a rotational speed of the engine crankshaft of $n=2200$ rpm indicates that when the engine runs on rich mixtures ($\alpha=0.7$), the exhaust gases contain up to 8% of carbon monoxide by volume. As one switches to lean mixtures, the CO content declines sharply, and when $\alpha=1.2$, it amounts to fractions of 1%. The content of other noxious substances also changes markedly with α. If we sum up the α dependences of all the toxic components (or even their majority), while at the same time using the "specific toxicity of exhaust gases" introduced by LANE and explained in §4 of Chapter 1, then for the GAZ-51 engine we shall have a dependence (Fig. 18) which shows that the minimum noxiousness of the exhaust gases occurs at α=1.18-1.25.

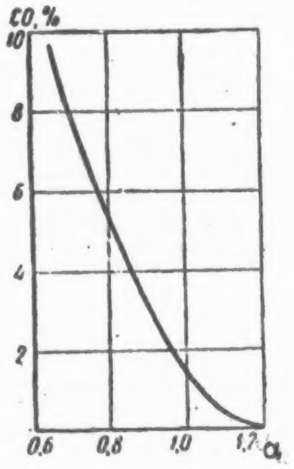


Fig. 17. Dependence of carbon monoxide content in the exhaust gases of GAZ-51 engine on the composition of the mixture. Speed of rotation of engine crankshaft n = 2200 rpm.

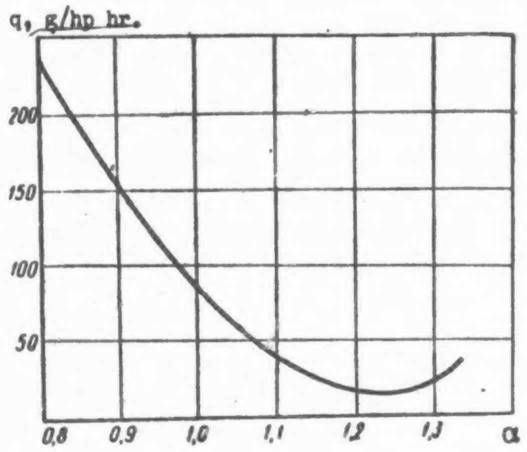


Fig. 18. Mixture-adjusted characteristic of specific toxicity of exhaust gases of GAZ-51 engine.

This value of the optimum excess air coefficient is characteristic of a specific engine developing power at a given rotational speed of the crankshaft. In order to be able to evaluate the performance of the engine from the standpoint of minimum fouling of the atmosphere by its exhaust in operation under all types of conditions, and to determine how the engine should be adjusted, a whole series of dependences characterizing its operation should be obtained. Such dependences should include the following:

characteristics of minimum toxicity of the exhaust gases, i. e., dependences showing what minimum values of the noxiousness of the exhaust gases can be achieved when the engine is properly adjusted and operates at different loads;

characteristics of optimum adjustment for toxicity, suggesting how the engine should be adjusted, i. e., what values of the excess air coefficients α should be set in relation to the power developed by the engine.

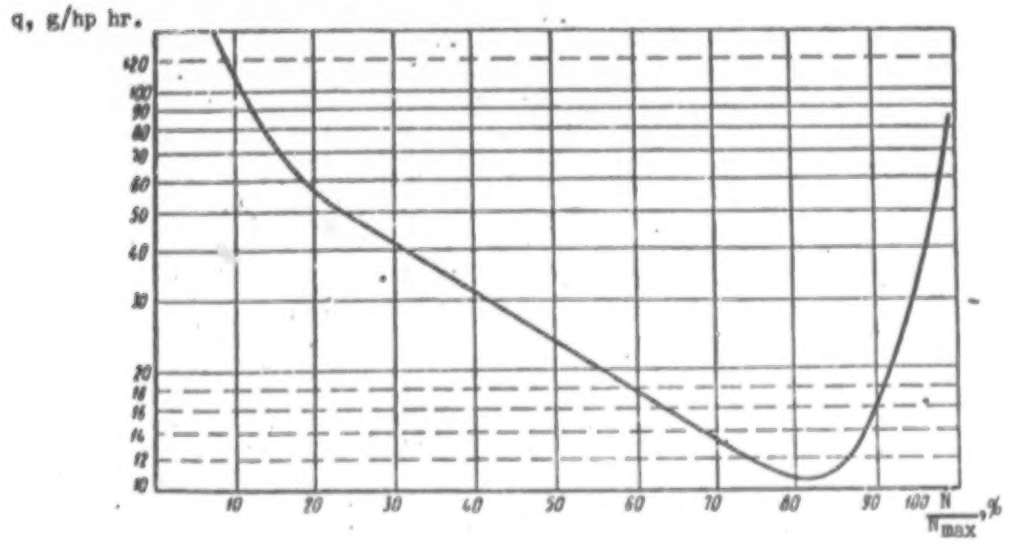


Fig. 19. Characteristic of minimum toxicity of exhausts of GAZ-51 engine.

Fig. 19 shows the characteristics of minimum toxicity of exhaust gases of the GAZ-51 engine, indicating that when the engine is properly adjusted and its load is 80% of the maximum power, the specific toxicity of the exhaust gases which can be achieved is barely above $q_e = 10$ g/hp hr. To reduce the height of the graph when it is plotted, the vertical axis represents the logarithms of the specific toxicity of the exhaust gases rather than the straight values of this toxicity.

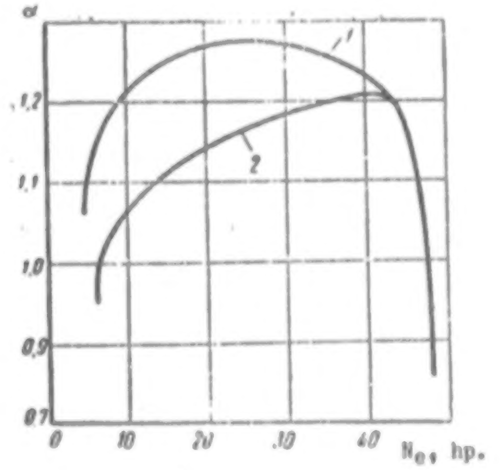


Fig. 20. Characteristics of optimum adjustment for the GAZ-51 engine:
1 - for toxicity; 2 - for economy.

The indicated characteristics can be obtained in automobile plants and large service centers with test stands. This work is complex and time-consuming. After correlating a large amount of experimental material, LANE was able to set forth a series of recommendations which should be followed in the daily practice of adjusting engines.

Usually, every engine today has known characteristics of its optimum adjustment for economy, obtained in the plant. Such characteristics for the GAZ-51 engine in its standard version (compression ratio ε=6.2; displacement V=3.48 l), operating at a crankshaft speed of 2000 rpm, are illustrated in Fig. 20.

The same graph shows the characteristics of optimum toxicity adjustment for the same engine, obtained at LANE. Comparison of the curves shows that under part-load conditions, the optimum values of α for toxicity are approximately 0.1 greater than for fuel consumption, i. e., they are shifted toward leaner mixtures.

Adjustment for conditions close to maximum power for both minimum toxicity and minimum specific consumption of fuel coincide. This is also observed at other rotating speeds of the crankshaft and in other engines. From this one can draw a practical conclusion. In order to minimize the toxic engine exhaust components that poison the atmosphere, the engine should be adjusted for leaner mixtures in the range of part loads (on the average, for values of α 0.1 greater than those required by the principle that the best economy of its operation must be achieved), leaving the adjustment for the specific fuel consumption unchanged in the range of loads close to the maximum.

This recommendation should be followed for all carburetor engines not equipped with special devices (catalytic neutralizers) for flameless afterburning of carbon monoxide present in the exhaust gases.

If the engine has a catalytic neutralizer, its adjustment for the excess air coefficient may be different. Dependences of the specific toxicity of the exhaust gases of a single-cylinder experimental engine obtained at LANE and calculated only in terms of nitrogen oxides at different angles of ignition advance are shown in Fig. 21. The engine had a compression ratio ε=7.5. The characteristics were plotted at a rotating speed of the crankshaft n = 1200 rpm and a volumetric efficiency η_V = 0.75. A distinctive feature of the graph is the fact that the given values of emission of nitrogen oxides were not referred to a unit of effective shaft power developed by the engine but to a unit of indicated power, i.e., the power of operation of the gases in the cylinder itself. In other words, the mechanical loss in the engine was not considered. This is entirely immaterial in an analysis of the nature of the variation of exhaust toxicity with the excess air coefficient.

It is evident from the figure that the maximum specific emission (i. e., per unit of indicated power) of nitrogen oxides corresponds to α = 0.95-1.1

for all values of the angle of ignition advance. As the mixture becomes leaner or richer, the specific emission of nitrogen oxides by the engine decreases. It is noteworthy that a greater decrease is associated with rich mixtures. Thus, in order to obtain the minimum content of nitrogen oxides in the engine exhausts, it is desirable to switch to richer mixtures. Although the carbon monoxide content of the exhaust will thus be increased, this is allowable for an engine equipped with a catalytic neutralizer.

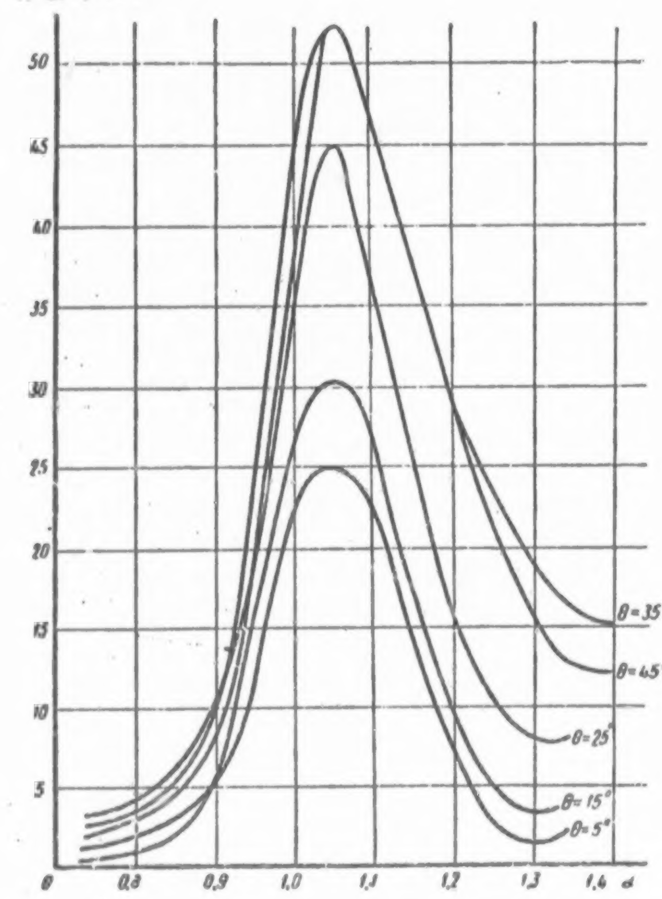


Fig. 21. Dependence of the indicated toxicity (referred to the indicated power) of exhaust gases of a single-cylinder experimental engine in terms of nitrogen oxides on the mixture ratio at different angles of ignition advance.

In summarizing the above, it should be noted that in providing the engine with a catalytic neutralizer, from the standpoint of achieving the lowest total toxicity of its exhaust gases, it is advisable to adjust the engine in the range of small loads for somewhat richer mixtures corresponding to $\alpha = 0.8\text{-}0.9$.

Since this recommendation implies a higher fuel consumption, it should be used only in individual cases. This applies primarily to the use of automobiles in poorly ventilated spaces (quarries, underground shafts, warehouses, etc.), when it is not necessary to consider the economy of operation of the engine.

The most important point in this case is to achieve the lower toxicity of the exhaust gases.

In diesel engines, the main adjustment parameters are the angle of injection advance θ, characterizing the start of the fuel feed, and the mixture ratio.

The time of the start of fuel injection greatly affects the process of fuel combustion. If the injection of the fuel is premature, a considerable part of it manages to vaporize, ignite, and burn up before the piston has reached the extreme upper position. The pressure in the cylinder increases rapidly and reaches high values, but this does not result in an increase of engine power, since the heat loss to the cooling water increases, and the gas pressure only interferes with the gradual motion of the piston. Late injection of fuel causes most of the latter to burn up while the volume above the piston expands. Thus, the maximum combustion pressure, average pressure per cycle, and engine power decrease, while the fuel consumption increases. Every diesel engine has its own optimum angle of injection advance, whose setting, other things being equal, ensures the development of maximum power and the best economy of the engine. The magnitude of the optimum angle of injection advance depends on many factors, particularly on the grade of fuel employed, and may vary over wide limits. For example, it is equal to 15° for the YaAZ-204 engine. The magnitude of the optimum angle of injection advance is usually indicated in the engine certificate.

As was shown by the studies, from the standpoint of the conditions favoring the development of the greatest power and best economy of operation, the optimum angle of injection advance, adjusted on the engine, also turns out to be optimal from the standpoint of the minimum total toxicity of its exhaust gases.

The toxicity of the exhausts of diesel engines is determined to a large extent by the composition of the mixture. Incomplete combustion in such engines begins at excess air coefficients greater than in carburetor engines. It is chiefly manifested in the appearance of soot in the exhausts. The excess air coefficient of diesel engines is decreased with increasing fuel feed, since the amount of entering air is practically constant for the same rotating speed of the crankshaft.

In the practical operation of diesel engines, when the composition of the working mixture is evaluated quantitatively, instead of the concept of the excess air coefficient, use is sometimes made of the quantity "fuel-air," representing the ratio of the amount of fuel injected into the cylinders to the amount of admitted air. Its relationship to the excess air coefficient is expressed by the formula

$$\alpha = \frac{G_a}{G_f} \times \frac{1}{l_0},$$

where l_0 is the amount of air theoretically required for the combustion of 1 kg of fuel (for diesel fuel $l_0 \approx 14.3$ kg of air per 1 kg of fuel).

If little fuel is supplied to the cylinders, the exhaust gases are practically colorless. As the fuel feed increases and reaches a certain value, considerable soot appears in the exhausts, and their color turns black.

Numerous studies have established that from the standpoint of sanitary considerations, it is most desirable to run diesel engines at $\alpha = 1.30-1.40$. As α decreases to 1.1-1.2, the power of the engine increases, but at the same time the fuel consumption rises and the toxicity of the exhausts increases considerably.

Usually, plant tests of diesel engines record characteristics 1 (Fig. 22), i. e., the smoking limit, representing the dependence of the power developed by the engine on the rotating speed of the crankshaft, i. e., $N_e = f\ (n)$. Each point of this curve corresponds to values of N_e and n characterized by a smoky emission of gases. In order to prevent the diesel engine from running under such conditions, the displacement of the controlling part of the fuel pump (usually the control lever) is restricted mechanically to limit the increase of the fuel supply by installing a stop. Thus, the maximum power which can be reached while the engine is running is obtained by installing a control of the stop. The relationship of the maximum operational values of the power to the rotational speed of the crankshaft is determined in this case by a fixed setting of the control element in the indicated position and is represented by a dependence referred to as the external operating speed characteristic is located below the smoking limit characteristics.

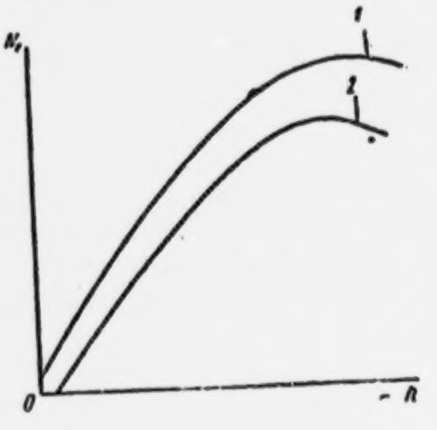


Fig. 22. Smoking limit characteristic (1) and external operating speed characteristic (2) of a diesel engine.

Frequently, diesel engines smoke because the manufacturing plants and sometimes individual automobile drivers reduce the gap between the maximum permissible operating power of a diesel engine and the power at which black smoke appears in the exhausts. Since the above-described characteristics are close to each other, any slight malfunction of the engine (impairment of atomization, maladjustment of valves, clogging of air filters, etc.) or change in the operating conditions of the automobile (moving to a mountainous area where the air is more rarefied than normal air) causes the appearance of a large amount of soot in the exhausts.

The installation of limiters of control elements of the fuel pump should be followed closely so as not to permit their arbitrary readjustment.

3. Technical Condition of Engine

Analysis of the malfunctions and wear of automobile engines has shown that the technical condition of automobiles has a considerable effect on the composition of their exhaust gases. It is evident from Fig. 23 that in terms of carbon monoxide, the exhaust gases of an old engine are 2-4 times as toxic as those of a new one. It is noteworthy that the highest toxicity corresponds to slow speeds of the automobile, i. e., those at which the automobiles travel in large cities a considerable part of the time.

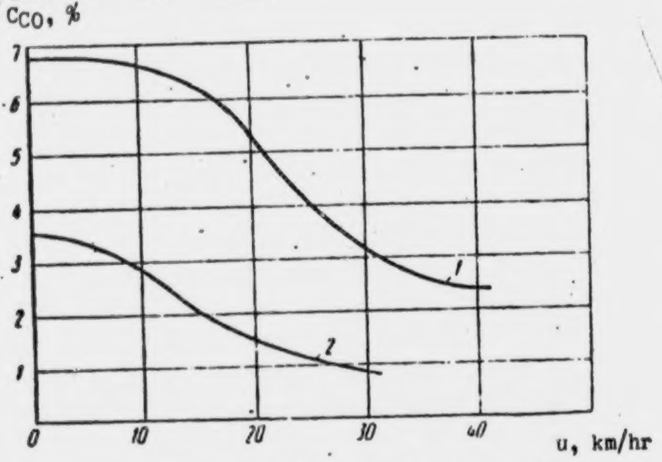


Fig. 23. Carbon monoxide content in the exhaust of a carburetor engine versus speed of automobile:
1 - used engine; 2 - new engine

The factors having the greatest influence on the toxicity of exhaust gases are malfunctions of the fuel system, chiefly the carburetor. Therefore, any malfunction causing a change of α (most frequently in the direction of its decrease) immediately affects the overall toxicity of the exhausts.

Table 6

Traveling Speed of Automobile, km/hr	Carbon Monoxide Content, % by Volume	
	Engine in Good Technical Condition	
	With Properly Adjusted Carburetor	With Carburetor Causing Excessive Fuel Consumption
Idling	1,5	4,5
10	1,5	4,0
15	--	—
20	0,2	2,8
30	0,2	3,2
40	0,2	—
50	1,2	—

Table 6 lists data on carbon monoxide concentrations in the exhaust gases of a ZIL-120 carburetor engine. The engine, which was in good technical condition, was sucessively tested with two carburetors:

a) properly adjusted;
b) producing an excessive fuel consumption.

A change in the composition of the mixture may be caused by the following factors:

clogging of main and auxiliary fuel jets;
sticking of carburetor choke;
clogging of air filter;
malfunction of carburetor float.

Defects of the piston rings, cylinder sleeves, and valve seats cause loss of compression, and hence, an impairment of the normal process of combustion leading to an increase in the content of toxic products of incomplete combustion in the exhaust gases. Furthermore, part of the gases break into the crankcase and, after mixing with the oil vapor, also escape into the atmosphere. The minimum amount of gases breaks through during idling and at low rotational speeds of the crankshaft, and the maximum when the choke is wide open. In the range from 800 to 2800 rpm, an average of 48 l/min of gases break through in a new GAZ-51 engine with a wide-open choke. In a medium-used engine, this figure increases to 75 l/min (a 1.55-fold increase) and in a worn engine it goes up to 123 l/min (a 2.55-fold increase over the initial value).

The electrical system of the automobile must be constantly checked and maintained in good technical condition.

Contamination of the spark plugs and malfunctions of the ignition system may cause spark failure. Then the unignited fuel-air mixture and the combustion products left over in the cylinder from the last cycle are completely ejected into the atmosphere. Gasoline vapor also is toxic, particularly the vapor of ethyl gasoline.

An impairment of the valve adjustment or malfunctions in the gas distribution system also cause an increase in the toxicity of the exhaust gases.

In diesel engines, the factors increasing the toxicity of the exhausts are:

1. clogging of the air filter;
2. defects of cylinder sleeves, and piston rings, and wear of valve seats, causing a decrease of compression;
3. malfunctions or maladjustment of the gas distribution system;
4. clogging of the exhaust pipe, which increases the exhaust counterpressure, impairs the course of the combustion process, and leads to a sharp increase of the soot content in the exhaust gases;
5. malfunctions of the feed system, including leakage of injectors, clogging of nozzle openings, sticking of injector valves, breakdown of injector valves springs, etc.

Of particular importance for the composition of the exhaust gases is the condition of the injectors. Table 7 shows the degree of change of the composition of exhaust gases as a function of the replacement of old injectors by new ones in the engine of an MAZ-525 dump truck operating under close to maximum load.

Table 7

Components of Exhaust Gases	Content of Components, % by Volume, with the Following Injectors:		Change in the Content of Components, % of Initial Volume
	Old	New	
Oxygen	18,05	10,96	61
Nitrogen	80,05	82,50	103
Carbon Dioxide	1,35	6,[illegible]0	480
Carbon Monoxide	0,31	0,[illegible]9	26
Acrolein	0,003	0,0006	20
Formaldehyde	0,0001	None	—

4. Leaning Out of Mixture, Ignition With High Energy Spark, Flame Ignition

As was shown in §2 of the present chapter, the toxicity of exhaust gases of carburetor engines may be reduced by switching to operation with leaner mixtures than required by the conditions of maximum economy developed by the engines. However, it is known from practical operation of automobiles that actual adjustment of engines usually tends to enrich the mixtures. This is done because, when very lean mixtures containing little fuel are used, the mixture may fail to be ignited by the spark. Therefore, drivers, erroneously trying to increase the reliability of the engine's operation and ignoring the economy let alone the toxicity of the exhaust gases, adjust the carburetor for a rich mixture. This is entirely superfluous, however. Modern engines with sufficiently high compression ratios operate stably when the carburetor is adjusted for economically optimal values of the excess air coefficient over the entire range of variation of the engine power. Furthermore, experiments have shown that with special ignition, the engine can run satisfactorily on still leaner mixtures, even at excess air coefficient values greater than $\alpha = 2$.

However, in order to obtain a stable and reliable operation of the engine on very lean mixtures, it is necessary to make sure in some way that when the spark is supplied to the cylinder, there will be the possibility of generation of a strong initial combustion source from which the flame will be able to spread freely over the entire volume of the fuel-air charge.

To date, two fundamentally different methods of producing such sources have been developed. The first consists in creating a high energy spark. The second provides for a change of the engine construction such that a small volume of a rich, easily igniting mixture is produced in the immediate vicinity of the standard ignition spark plug before the spark is produced. The combustion of this volume forms an intense and powerful ignition source which makes it possible to burn very lean mixtures as well. The method includes a laminar distribution of the mixture and prechamber-flame ignition. There are many designs of prechamber-flame ignition. They differ from one another in the methods of feeding the fuel to the prechamber, methods of mounting on the engine, etc., but the principle of their operation is the same.

Experimental studies conducted at LANE have made it possible to compare the change of the toxicity of carburetor engine exhausts by using three types of ignition: standard, high energy spark, and prechamber-flame ignition. All the experiments were performed on the same GAZ-51 engine.

An ignition system developed by the Scientific Research Institute of Automatic Instruments (SRIAI) was used to ignite a mixture with a high energy spark. It consists of a system of battery ignition with semiconductor commutation of the primary circuit. Large inductive resistances which made it possible to raise the voltage at the spark plug electrodes to 30,000 V and increase the discharge time to 0.003 sec were introduced into the commutation system. The prechamber-flame ignition used was the one developed at the Central Scientific Research and Experimental Design Institute of Fuel Apparatus of Tractor and Stationary Engines. Its technical characteristics are: volume of prechamber 1.5 cm^3, automatic mixture supply valve actuated by pressure difference. The mixture is formed in the float chamber of the carburetor through enrichment of the fuel with light, rapidly evaporating fractions. In order to modify the engine to a prechamber-flame ignition system, the carburetor must be replaced, and adapters with prechambers screwed onto the spark plugs.

The advantages and disadvantages of all the enumerated ignition systems can be readily compared in terms of the characteristics of minimum toxicity of exhaust gases (Fig. 24) plotted by taking into account the main standardizable toxic components of the aerosol. The characteristics were plotted on a semilog scale, i. e., the loads in percent were laid off along the horizontal axis, and logarithms of the values of the specific toxicity of the exhaust were laid off along the vertical axis. The shape of the curves defining these relationships was found to remain unchanged.

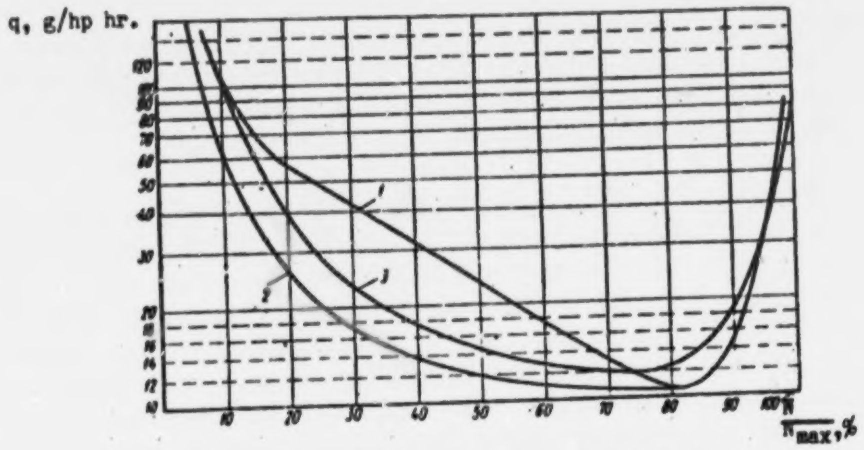


Fig. 24. Characteristics of minimum toxicity of exhaust gases of GAZ-51 engine obtained by using different ignition systems:

1 - standard ignition; 2 - ignition with high energy spark; 3 - prechamber-flame ignition.

Comparison of minimum toxicity characteristics shows that leaning out of a mixture with simultaneous intensification of ignition strongly depresses the toxicity of the engine exhausts at part loads. The best results are obtained with a high energy spark ignition system according to the SRIAI circuit, which reduces the total toxicity of the gases by a factor of 2-3. A somewhat lesser effect is obtained by using prechamber-flame ignition. In this case, the toxicity of the exhausts is reduced by a factor of 1.8-2.5 as compared with the standard system. The better result obtained by using high energy spark ignition is explained by the fact that it lacks the additional source of formation of carbon monoxide which in the prechamber-flame ignition is constituted by the initial, small, but highly enriched volume of the fuel-air charge.

Engines with prechamber-flame ignition and the SRIAI intensified ignition system are completed under laboratory conditions.

Inasmuch as the use of the prechamber-flame ignition principle, in addition to reducing the toxicity of the exhaust gases, results in a 3-5% rise in the economy of engine operation, many automobile factories in this country, particularly ZIL (Plant im. Likhachyev) and GAZ [Gor'kiy Motor Vehicle Plant (im. V. M. Molotov)], are developing engines with prechamber-flame ignition.

Thus, the changeover to lean mixtures makes it possible to decrease the toxicity of the exhaust gases of carburetor engines in terms of the components which are standardizable at the present time. However, how can this rule always be followed if it is known that all modern carburetors are adjusted in such a way that they give a rich mixture in the range of 80-100% of throttle opening? Is it possible to switch to lean mixtures in this case?

It is possible indeed. However, the engine design must specify the devices that could compensate for the power loss that must take place in the changeover to lean mixtures in the range of large engine loads. One such device can be the super-charger, mounted in the intake system.

In this case, while the total amount of gasoline supplied to the cylinder is maintained constant, α is increased by force-feeding a large amount of air under pressure.

The power losses which must be offset by pressure charging in certain engines are given in Table 8. Here a leaning out of the mixture to $\alpha=1.12$ is assumed.

Table 8

Engine	Rotating Speed of Crankshaft rpm	α at Maximum Power	Power Decrease	
			Hp	%
GAZ-20	1000	0,85	2,4	15,2
	2000	0,90	4,4	12,6
GAZ-21B	1000	0,95	1,4	8,5
	2000	0,95	1,4	4,0
	3000	0,90	10,7	20,8
ZIL-120	1200	0,87	7,4	14,2
	1600	0,93	10,4	14,4
	2000	0,88	10,8	13,4

It is obvious from Table 8 that in the changeover to lean mixture, from 4 to 21% of the power thus lost must be compensated for. Experiments show that pressure charging makes it possible to accomplish this. Without risking the appearance of knocking, pressure charging can provide a power increase of up to 26%. LANE also established that:

In order to achieve a low-toxicity and economic operation of a multi-cylinder carburetor engine in the load range of 85-100%, a changeover to lean mixtures with compensation of the power loss by pressure charging is desirable;

Engines with an adequate distribution of the mixture over the cylinders make it possible to lean out the mixture to $\alpha=1.2$ at full power, and those with a poor mixture distribution, to $\alpha=1.12$. Thus the power is preserved by pressure charging, and the toxicity of the exhaust gases decreases by a factor of 12 in engines with a good mixture distribution and 10 in those with a poor distribution.

It should be noted that when a pressure-charging supercharger is installed on an engine, it is necessary to change the gas distribution phases to some extent, since, during the increase of the pressure of the fuel-air mixture entering the cylinder at the instant of valve overlap, a certain seepage of the fresh mixture into the exhaust pipe is possible.

5. Vacuum Regulator

In order to improve the economy of operation of an engine and decrease the toxicity under forced idling conditions, it was proposed in this country back in the 1940's that a device be introduced into the carburetor design which automatically disconnects the idling jet as soon as the engine is shifted to forced idling. As was pointed out by Academician Ye. A. Chudakov, "Comrades Rubets, Kravtsov and Varenov, who proposed such an attachment for domestic introduction, called it a vacuum stabilizer." Later this name was changed. Since the use of the vacuum stabilizer yields a certain economy of gasoline, it received the name of idling economizer.

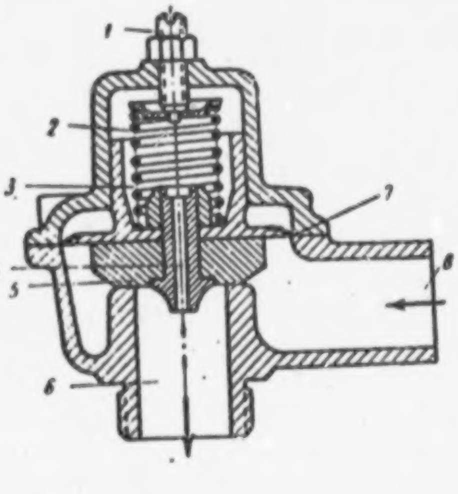


Fig. 25. Diagram of Vacuum Regulator (AESRI).

For the same purposes, the Automobile Engine Scientific Research Institute (AESRI) designed a vacuum regulator also called the coasting valve. Its principle of operation is analogous to that of the idling economizer.

The purpose of this regulator is to admit an additional amount of air into the intake system of the engine operating under forced idling conditions.

A diagram of the vacuum regulator is shown in Fig. 25. Valve 5 separates two cavities: 6, connected to the intake manifold, and 8, connected with the atmosphere. Cavity 3 above the valve communicates through channel 4 with the cavity of the intake manifold. Diaphragm 7 is the element that opens the channel. Screw 1, which changes the initial tension of spring 2, is used to adjust the vacuum in the intake manifold at which the valve should open.

The vacuum regulator operates in the following manner. As the pressure in the intake manifold drops below the value corresponding to idling, diaphragm 7 rises (the total pressure exerted on it from the top is less than from the bottom) and opens the valve. An additional amount of air enters the intake manifold, and the vacuum in the latter decreases (the pressure increases). The vacuum also decreases in cavity 3 above the valve, since this cavity is connected with the intake manifold via channel 4. The valve is closed by the action of the spring.

6. Use of Fuel Additives

The complete combustion of fuel and hence a reduction in the content of certain toxic components (carbon monoxide, aldehydes, hydrocarbons, soot and other components) in the exhaust gases can be achieved by diluting the fuel with special agents, i. e., additives altering the course of the oxidation reactions of hydrocarbons. The additives may be alcohols, their mixtures, individual homogeneous petroleum distillation products, or complex compounds of the most diverse substances, added to fuels in amounts ranging from a fraction of a percent to several tens of percent.

For carburetor engines, the most effective of those known at the present time are mixtures of different alcohols. They have been studied at the All-Union Scientific Research Institute of Petroleum Refining (AUSRIPR). Some results of experiments on the determination of the effectiveness of adding a mixture of alcohols to standard A-72 gasoline, conducted for the purpose of decreasing the content of carbon monoxide in engine exhausts, are shown in Table 9. The experiments were set up under bench conditions using GAZ-21D and MZMA-407 engines operating at 50% of maximum load and at a crankshaft speed of 2000 rpm.

It is evident from Table 9 that a substantial reduction of the carbon monoxide content of the exhaust gases can be achieved by adding an alcohol mixture to the gasoline. In some cases, carbon monoxide is completely absent from the gases.

Table 9

Fuel	Engine	Excess Air Coefficient α	Carbon Monoxide Content of Exhaust Gases, %	
			By Volume	For Initial Volume of
A-72 gasoline	GAZ-21Д	—	1,20	100
Same	MZMA -407	0,910	1,07	100
A-72+4% alcohols	GAZ-21Д	0,978	0,80	67
Same	MZMA -407	0,927	0,65	61
A-72+8% alcohols	GAZ-21Д	0,964	0,60	50
Same	MZMA -407	0,950	0,40	38
A-72+12% alcohols	GAZ-21Д	0,950	0,50	42
Same	MZMA -407	0,945	0,12	11
A-72+16% alcohols	GAZ-21Д	0,946	0,40	33
Same	MZMA -407	0,965	0,0	0
A-72+20% alcohols	GAZ-21Д	0,950	0,20	17
A-72+24% alcohols	MZMA -407	0,935	0,0	0

Similar results were obtained for gasolines of other brands.

Apparently, the addition of a mixture of alcohols to gasolines decreases the content of not only carbon monoxide in the exhaust gases, but also of other products of incomplete fuel combustion, in particular, aldehydes. No direct experiments with a complete chemical analysis of the composition of the exhaust gases have as yet been set up. There is reason to believe that the addition of alcohols can lower the content of carcinogenic substances in the exhaust gases. It should be noted that the addition of alcohols further reduces the formation of deposits in the engines, increases their power, and improves the economy of operation by an average of 5%. At the present time, the problem of the usefulness of adding alcohol mixtures to gasoline is being comprehensively studied.

In developing additives to diesel fuels, attention is focused primarily on reducing the soot in the exhaust gases, i. e., decreasing their smoke content.

Additives are being developed in many countries. In particular, an additive under the brand name of SLD has been developed in Belgium, which among other components includes 19% barium, 1.5% sulfur, and 32.5% sulfur slags. In liquid form, the additive is added in amounts of 0.25 to 1.0% of the fuel volume.

The company tested the additive for 240 hr in a single-cylinder four-stroke prechamber test engine with a compression ratio $\varepsilon=19$ and displacement $V=553$ cm^3. During the tests, the dimensions of the moving parts of the engine (piston rings, cylinder sleeve, etc.) were measured, chemical analysis of the lubricating oil was carried out, and the content of soot, carbon monoxide, aldehydes, and nitrogen oxides in the exhaust gases was determined.

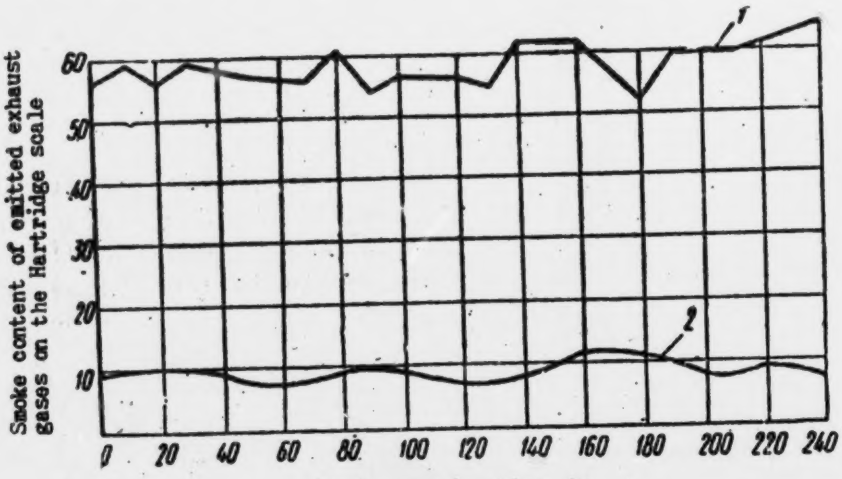


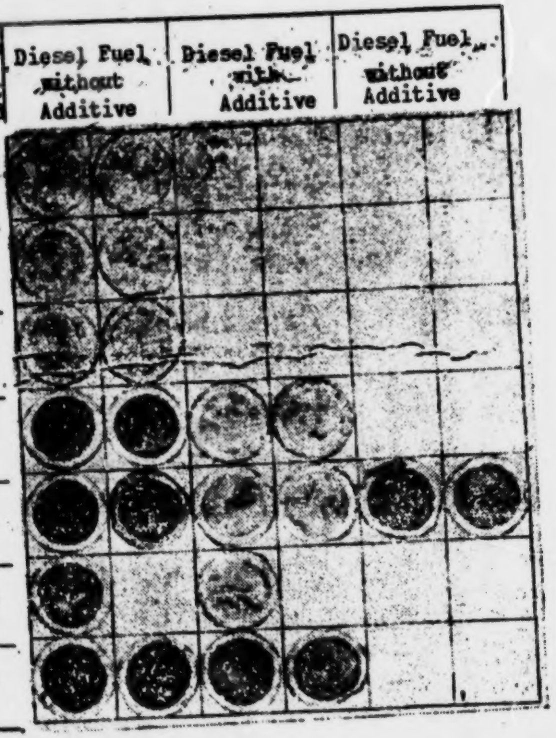
Fig. 26. Change in the smoke content of exhaust gases:
1 - without additives; 2 - with SLD additives

It was found that dilution of the fuel with the SLD additive has no adverse effect on the lubricating oil, does not clog up the fuel feed system, does not increase the wear of the moving parts, and does not affect the content of carbon monoxide, aldehydes, and nitrogen oxides in the exhaust gases. At the same time, the smoke content of the latter decreases by a factor of 10 or more. Fig. 26 shows the curves advertised by the company and representing the change of the smoke content of exhaust gases during the operation of an engine when the SLD additive is used. The smoke content values are given in Hartridge units.

Laboratory samples of the most varied liquid additives were tested at LANE. The test results for one of them (containing barium), conducted on two automobile engines, the two-stroke YaAZ-204 and four-stroke YaMZ-236 engine, are shown in Figs. 27 and 28 and Table 10.

The figures show photographs of absolute BF filters through which were passed equal volumes of exhaust samples taken from the exhaust manifolds of the engines.

Number of Conditions	Rpm of Crankshaft	Operating Conditions & Load hp	Pressure in Exhaust Manifold mm H_2O
1	1400	Idling	500
2	1400	28 hp	566
3	1400	56 hp	667
4	1400	84 hp	800
5	1400	112 hp	900
6	1400	56 hp	5000
7	1200	72 hp	6000


Diesel Fuel without Additive
Diesel Fuel with Additive
Diesel Fuel without Additive

NOT REPRODUCIBLE

Fig. 27. Condition of BF filters of YaMZ-236 engine operating on fuel with and without additive.

NOT REPRODUCIBLE

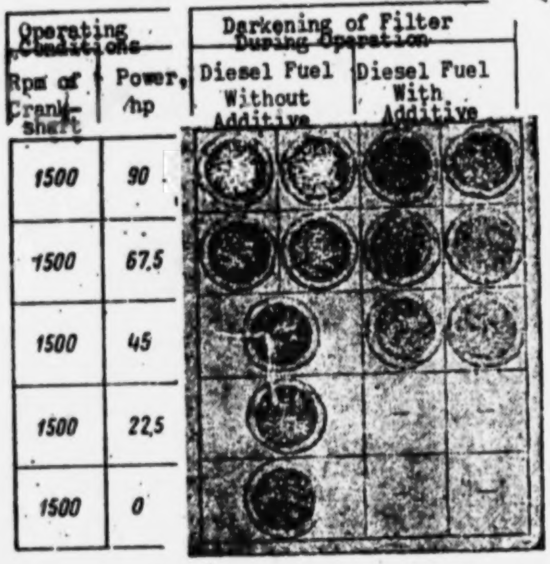

Operating Conditions
Rpm of Crankshaft
Power, hp
Darkening of Filter During Operation
Diesel Fuel Without Additive
Diesel Fuel With Additive
1500
90
1500
67.5
1500
45
1500
22.5
1500
0

Fig. 28. Condition of BF filters of YaAZ-204 engine operating on fuel with and without additive.

In the Soviet Union, effective antismoking, metal-containing additives have been developed by the Institute for Chemistry of Additives, Academy of Sciences of the Azerbaijan SSR. Their use decreases the smoke content of diesel engine exhausts and lowers the emission of carcinogenic substances into the atmosphere by up to 60%.

A positive solution to the problem of widespread adoption of additives in the national economy should also be preceded by a comprehensive analysis of a large number of specific problems. These include:

Study of the effect of additives on the content of all or most of the toxic components of exhaust gases. It may also happen that the addition of some additive to the fuel will cause the appearance in the gases of new noxious substances which earlier had been absent;

Study of the effect of additives on the power, economic and other indices of operation of engines;

Study of the effect of additives on the parts and systems of the engines and on the lubricating oil;

Development of the technology of industrial production of additives;

Development of industrial equipment for the production of additives in necessary amounts and equipment for their storage;

Estimation of the cost of production of additives and calculation of the capital investment necessary for constructing the plants or individual plant sections.

Table 10

Experiment Number	Operating Conditions of Engine		Exhaust Counter-Pressure mm H_2O	Content of Exhaust Gases in Hartridge units		Decrease of Smoke Content, %
	Power, N_e, hp	Rotational Speed of Crankshaft, rpm		Fuel Without Additive	Fuel With Additive	
1	Idling	1400	500	5,5	—	—
	Idling ход	1400	500	4,5	—	—
2	28	1400	566	3,5	—	—
	28	1400	566	3,5	—	—
3	56	1400	667	5,0	—	—
	56	1400	667	5,5	—	—
4	84	1400	800	20,0	3,5	82,5
	84	1400	800	20,0	3,5	82,5
5	112	1400	900	43,5	6,0	86,0
	112	1400	900	47,5	7,5	84,0
6	56	1400	5000	17,0	2,5	85,5
7	72	1200	6000	58,0	19,0	67,0
	72	1200	6000	44,0	13,5	69,0

Note. In experiments Nos. 6 and 7, the increased exhaust counterpressure was reduced by interposing a specially mounted gate valve.

These problems are being solved at the present time, and there is good reason to believe that definitive conclusions will be reached in the immediate future.

Chapter IV

NEUTRALIZATION OF TOXIC COMPONENTS OF EXHAUST GASES

One of the most common methods of purification of noxious gases consists in passing them through various devices. The latter either trap the toxic substances by precipitating (absorbing) them on the surface of the filler or dissolving them in liquids, or chemically bind the noxious components of the gases first, then trap the products of the chemical reactions.

Occasionally, in order to ensure the occurrence of these processes, it is necessary to subject the gases to the action of electric or ultrasonic fields. Accordingly, the devices are then called electric or ultrasonic.

There are designs that actively affect the components of exhaust gases. Such designs can be used to complete the combustion of unburned components of the gases and to carry out various chemical transformations of individual substances.

The degree in development of such devices is so advanced that it theoretically permits the creation of such designs that remove a gas of any composition to achieve any degree of purity.

From the standpoint of their principle of operation, all the devices for neutralizing engine exhausts are divided into two major groups. Those which merely block noxious substances are called filters. However, when used to actively effect changes in the component aerosols (afterburning of unburned components, chemical transformation of noxious substances, etc.), such devices are called neutralizers. The latter neutralize noxious substances, i. e., convert them into products which do not affect human health.

1. Liquid Neutralizers

Historically, liquid neutralizers were the first devices to find application in the partial detoxication of exhaust gases. They were developed especially in the mining industry, where they have been and continue to be installed on heavy-duty automotive equipment.

Their principle of operation is simple. The aerosol is passed through water or an aqueous solution of various chemical reagents where a part of the noxious substances (mostly in the solid state) is simply blocked mechanically, precipitating as a deposit, another part dissolves, and a third part is tied up chemically. At the same time, this causes the gas to cool down.

We shall consider the interaction of certain toxic components of exhaust gases with water and aqueous solutions of chemical reagents.

Aldehydes dissolve in water, light ones easily, and heavy ones (in particular, acrolein CH_2-CH-CHO) with more difficulty. As the temperature of the water rises and the latter becomes saturated, the solubility declines. As a result, after saturation, the water no longer dissolves aldehydes. If in addition, for whatever reasons, the water temperature rises, the aldehydes will begin to volatilize from the solution.

When the exhaust gases pass through aqueous solutions of salts, the aldehydes combine chemically, then the products of the reactions dissolve in the solutions. For example, the reaction between formaldehyde (HCOH) and an aqueous solution of sodium sulfite (Na_2SO_3) proceeds as follows:

$$Na_2SO_3 + HCOH + H_2O \rightarrow NaOH + CH_2(NaSO_3)OH,$$

where $CH_2(NaSO_3)OH$ is retained in the solution on the chemical reagent.

Nitric oxide is poorly soluble in water, while nitrogen dioxide is readily soluble, forming nitric and nitrous acids.

$$2NO_2 + H_2O \rightleftarrows HNO_3 + HNO_2.$$

The reaction is reversible, i. e., can proceed in both directions, causing an incomplete absorption of the dioxide. When the acids reach a certain concentration, the reaction shifts to the left, and the product of the reaction is the dioxide.

The oxide and dioxide are readily absorbed by aqueous solutions of a number of salts. In all of these reactions, an equilibrium is established between the initial and final products, similar to the one above. For this reason, the absorption of nitric oxide is incomplete. The degree of absorption of nitric oxide may be evaluated from the following data: one part of ferrous sulfate dissolved in two parts of water absorbs three volumes of nitric oxide; a saturated volume of ferric chloride absorbs 23 volumes of nitric oxide.

Both nitric oxide and nitrogen dioxide react well with strong aqueous solutions of acids and alkalis, which unfortunately strongly corrode the equipment and necessitate careful handling.

Soot (particularly coarse particles) is retained when a gas passes through water and aqueous solutions of chemical reagents, settling out as a deposit. When the solution is swirled, the deposit may be churned up. The soot particles are then caught by the passing gas and are carried away into the atmosphere.

Carbon monoxide reacts with neither water nor aqueous solutions of chemical reagents employed in practice. At the present time, studies are being made to find solutions retaining carbon monoxide.

It follows from the above that the use of water in liquid neutralizers is very limited. It can be used only as an emergency filler, when for whatever reasons, the entire stock of chemical reagents has been depleted where liquid neutralizers are used. Furthermore, the service period of the neutralizer must be shortened.

Aqueous solutions of sodium sulfate (Na_2SO_3), sodium carbonate (Na_2CO_3), sodium bicarbonate ($NaHCO_3$), ferrous sulfate ($FeSO_4$), sodium hydroxide ($NaOH$), copper acetate [$CH_3(CuO)_2$], their mixtures, and other solutions have been studied in various concentrations as chemical reagents for neutralizing exhaust gases. Analysis of the test results made it possible to select the most effective solutions. These were found to be ten-percent aqueous solutions of Na_2SO_3 or $NaHCO_3$ or Na_2SO_3 with an admixture of 0.5% hydroquinone ($C_6H_6O_2$), which prevents premature oxidation of the main chemical reagent. By passing the exhaust gases through these solutions, a complete neutralization of aldehydes and up to 70% of nitrogen oxides was achieved in the course of 8 hrs. Further use of the solution is possible, but the neutralization occurs at a slower rate. The solution should be replaced.

A high degree of neutralization of exhaust gases is also provided by a ten-percent solution of ferrous sulfate ($FeSO_4$) with an admixture of 0.5% hydroquinone. It allows a neutralization of 100% of the aldehydes and 70% of nitrogen oxides present in the gases. However, the performance of this solution is unstable. Under certain operating conditions of the engine, especially those characterized by a high content of nitrogen oxides in the exhaust gases, the solution ceases to absorb them altogether.

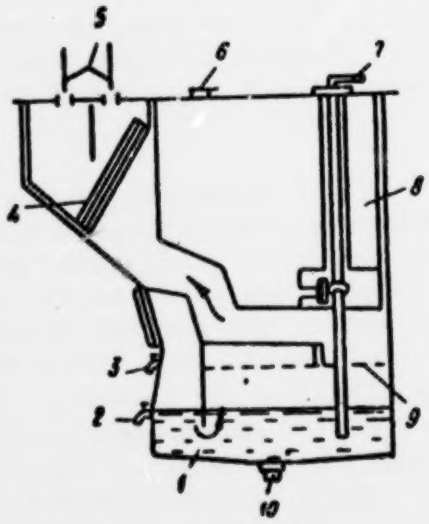


Fig. 29. Liquid neutralizer made by Salzhutter Co.

Liquid neutralizers are used for detoxicating the exhaust gases of diesel engines, since the main toxic component of carburetor engines is carbon monoxide, i. e., a component to which liquid neutralizers are insensitive. One of the most perfect modern liquid neutralizers is one produced by a West German company, Salzhutter (Fig. 29). The neutralizer consists of main tank 1 into which 70 l of the chemical reagent is poured, and auxiliary tank 8 with 200 l of pure water. To increase the cooling surface of the tanks, they are corrugated and covered with a porous coating. The path of the gas is indicated by arrows. The gas traverses the solution, a set of angle brackets 4 which separate the moisture droplets, and escapes into the atmosphere through outlet 5. As the neutralizer continues to be used, the amount of water in the solution of the chemical reagent decreases as a result of evaporation. The concentration of the solution increases, and its level drops. Tube 7, connecting the main tank with the auxiliary one, becomes exposed, and the auxiliary tank automatically delivers a certain amount of water to the solution, thus diluting it. This water is added until the level of the solution has covered the lower section of connecting tube 7. Orifice 6 is used to pour in the neutralizer, plug 10 is for draining the spent solution, and stopcocks 2 and 3 are used to control the level. The inner chambers of the apparatus are cleaned by removing the soot and scale through a hand hole. The neutralizer is mounted on a diesel-electric self-propelled wagon used in the mining industry.

At LANE, this neutralizer was tested on a stand with an YaAZ-204V engine. The chemical reagent used was a 10% solution of NA_2SO_3 containing 0.5% hydroquinone. The tests showed that depending on the operating conditions of the engine, a 90-100% removal of aldehydes and 35-70% removal of nitrogen oxides from the exhaust gases is achieved. After the neutralizer, the exhaust gases were practically colorless and had cooled down to temperatures no higher than 140° C. The temperature of the reagent solution was no higher than 70°. The neutralizer operated continuously for 8 hrs, after which the solution had to be replaced and water had to be added.

In collaboration with the State Experimental Institute of Design and Construction for the Coal-Machinery Industry, LANE developed a combination neutralizer for the engine of the VS-15 self-propelled wagon (YaAZ-204V diesel engine), the chief element of which was a liquid neutralizer. To remove carbon monoxide from the exhaust gases, the general scheme also included a special low-temperature catalytic neutralizer through which the gases were passed before entering the main tank containing the chemical reagent (see §3 of this chapter). The neutralizer was tested under road conditions. Under the most unfavorable operating conditions of the engine, the content of nitrogen oxides in the exhaust gases past the liquid neutralizer did not exceed 0.315 mg/l for a content of nitrogen oxides of 0.478 mg/l (degree of purification, 35%). The retention of aldehydes was practically total. Under most operating conditions of the engine, the exhaust gases were colorless and acquired a color only when the engine was raced.

During the construction of the Leningrad subway, tests were carried out on another liquid neutralizer developed at LANE (Fig. 30) specifically for TGK diesel locomotive with a 1D6 diesel engine. The diagram of the installation of the neutralizer on the locomotive is shown in Fig. 31. The tests were performed under the following operating conditions of the locomotive: parked, idle revolutions of the engine crankshaft; shunting speed of 30 km/hr; cruising speed of 60 km/hr. While moving, the locomotive was without load and with a load of 32 tons. The tests showed a satisfactory operation of the neutralizer. The exhaust gases contained almost no smoke, but did contain a large amount of moisture, mainly in the vapor state. Carryover of moisture droplets was observed only during cruising (when the locomotive traveled at 50 km/hr on a segment of road with a slope of 0.009). A sharp reduction of the toxic components of the exhaust gases took place. Even when the neutralizer was filled only with water, the aldehyde content decreased by 50%.

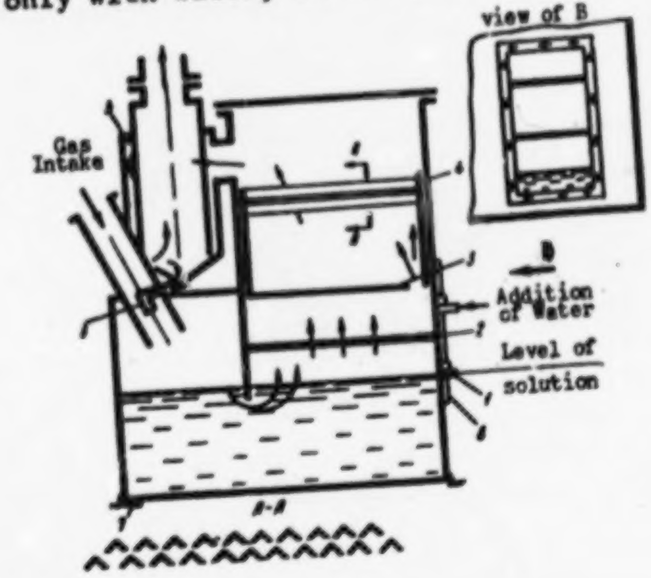


Fig. 30. Liquid neutralizer of exhaust gases of 1D6 diesel engine:
1 - control stopcock; 2 - damper; 3 - water guard; 4 - wall of water guard; 5 - cyclone; 6 - ejector tube; 7 - drain plug; 8 - sight hole.

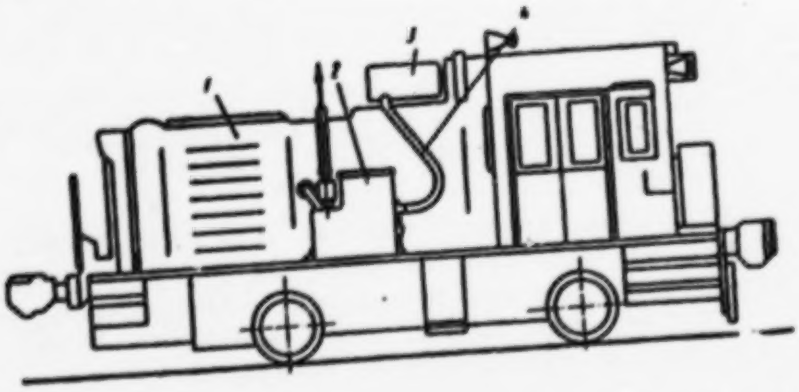


Fig. 31. Diagram of installation of LANE liquid neutralizer on TGK diesel locomotive:
1 - engine; 2 - neutralizer; 3 - replenishing tank with water; 4 - connecting hose.

Liquid neutralizers have earned the right to be mounted on diesel locomotives, self-propelled equipment, stationary power plants, etc. In some cases, namely, in closed spaces exposed to explosion hazard, they are simply irreplaceable, since, by simultaneously acting as coolers, they substantially lower the temperature of the exhaust gases. The main disadvantages of this type of devices are:

Large weight and outside dimensions;

Insensitivity to neutralization of carbon monoxide;

Complexity of servicing due to the frequent replacement of the reagent solution (as a rule, every eight hours of operation) and a periodic time-consuming cleanout of the inner chambers to remove the scale and soot (at least once every two weeks);

High cost of the chemical reagent;

Difficulties arising at subzero temperatures of the surrounding medium because of the possibility of freezing of the solution.

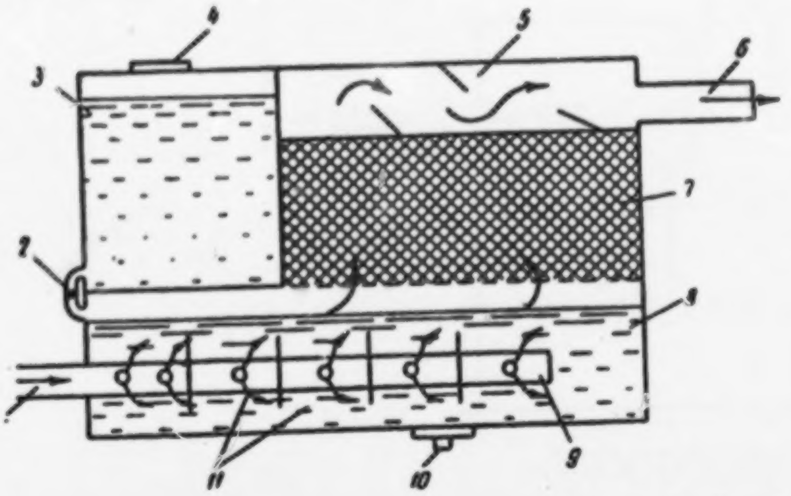


Fig. 32. Diagram of liquid neutralizer (designed by the Leningrad Mining Institute im. Plekhanov) for exhaust gases of diesel engine of MAZ-205 truck:

1 - gas intake; 2 - overflow stopcock; 3 - replenishing tank with water, capacity 45 l; 4 - replenishing orifice; 5 - water guards; 6 - gas exit; 7 - metal turnings; 8 - main tank, capacity 55 l; 9 - collector; 10 - drain plug; 11 - compartments.

These disadvantages account for the fact that liquid neutralizers thus far have not been commonly used in motor transport. Nothing has been published abroad on their use for detoxicating the exhaust gases of mass-produced automobiles. In the Soviet Union, a small original model of a neutralizer has been constructed at the Leningrad Mining Institute im. Plekhanov (Fig. 32).

Neutralizers of this type were installed on MAZ-205 dump trucks hauling rock from the excavation of by-pass tunnels during the construction of the Nurek Hydroelectric Power Plant built by "Tadzhikgidrospetsstroy" (Tajik Trust for the Reinforcement of Foundations and Structures of the Ministry of Electric

Power Plants of the USSR) and in other areas, and were connected only when the trucks were moving inside the tunnels. Thus, the conditions of operation of the dump trucks (periodically leaving and entering the tunnels) predetermined the repeated short-term operation of the neutralizers, causing a moderate temperature of the reagent solution in relatively small quantities of it. The climatic conditions of the construction site excluded freezing of the solution.

Work on improvement of liquid neutralizers continues. There are still many other ways of decreasing their weight and size, and eliminating a number of other drawbacks.

2. Flame Afterburning of Toxic Components of Exhaust Gases

The method of flame afterburning is based on the ability of the toxic fuel components of exhaust gases (carbon monoxide, aldehydes, hydrocarbons, etc.) to oxidize at high temperature and in the presence of free oxygen in a gas mixture. Nitrogen oxides are not neutralized by flame afterburners. A vigorous oxidation reaction of aldehydes requires a minimum temperature of 550°C and in the case of carbon monoxide and hydrocarbons, around 700°C. In carburetor engines, whose exhaust gases contain large amounts of carbon monoxide, flame afterburning can be carried out under certain operating conditions of the engines without the presence of a steadily acting high-temperature, strong open-flame source. The exhaust gases, first diluted with air (one must bear in mind that their initial oxygen content is low), can be ignited periodically by an electric spark. The combustion then proceeds on its own. A high flame temperature is sustained by the heat evolved during the combustion of the toxic components (the combustion of 1% by volume of CO contained in the gas mixture raises the temperature by approximately 100°C). A stable combustion will not always be sustained in this case. When the engine operates on leaned-out mixtures, the heat of the oxidation reactions of toxic components is no longer sufficient to sustain the flame, and therefore an additional amount of fuel must be added to the afterburner. In order to provide for a more stable operation of the neutralizer under variable operating conditions of the engine, the neutralizer design is made to include a heat exchanger to which air is supplied before entering the combustion chamber. The heat exchanger is heated by the gases during their combustion or before they are discharged into the atmosphere. An automatic by-pass valve is installed in the heat exchanger to protect it from overheating when the engine operates on rich mixtures. Fig. 33 shows a diagram of a flame neutralizer. Exhaust gases 1 enter afterburner 3, which has two ejectors supplying initial air 2 and secondary air 4; the latter is heated in the heat exchanger 7. Combustion takes place in chamber 6, and spark plug 5 provides the ignition.

Flame neutralizers of exhaust gases for carburetor engines have been developed and tested mostly abroad, particularly in the U.S.A. The tests have shown their inefficient and extremely unstable operation. In order to obtain a stable combustion, the combustion chamber is placed as close as possible to the exhaust valve, where the temperature of the exhaust gases is sufficiently high. Sometimes it is built directly into the exhaust manifold of the engine (Fig. 34).

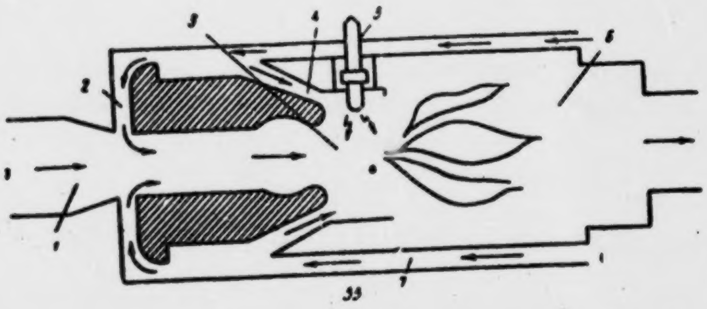


Fig. 33. Diagram of flame neutralizer of carburetor engine exhausts.

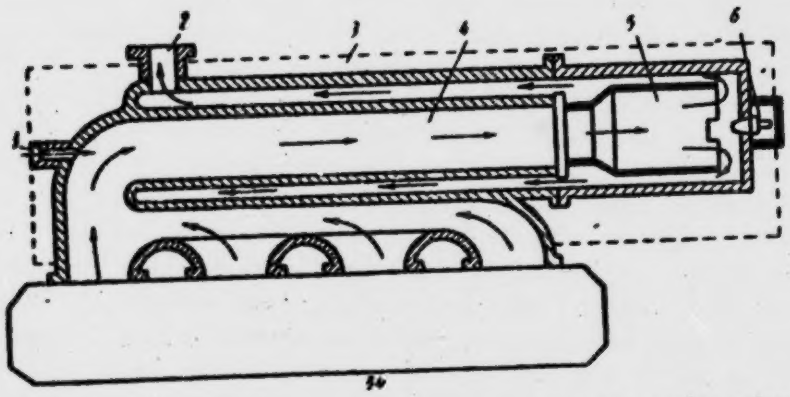


Fig. 34. Diagram of flame neutralizer of carburetor engine exhausts, built into the exhaust manifold:
1 - intake of extra air; 2 - release of gases; 3 - heat insulation; 4 - mixing chamber; 5 - combustion chamber; 6 - spark plug.

Closely related to the principle of flame afterburning is the method, developed in the U.S.A., of supplying extra air to the points of direct release of the exhaust gases from the cylinders. Here the extra air is supplied to the seats of the exhaust valves (in some designs even through the valve stems). In this case, owing to the high temperature of the exhaust gases, the chemical oxidation reaction of a series of incomplete combustion products (in particular, aldehydes) is achieved at full engine load without the presence of additional ignition. Such designs of exhaust systems are used on engines of automobiles produced by General Motors, Ford, etc.

In diesel engines, the afterburning of the unburned components of exhaust gases is possible only when they are passed through an open-flame source generated for this purpose. The best-known designs of flame neutralizers are those for MAZ-205 (Fig. 35) and MAZ-525 (Fig. 36) automobiles. With a correct automatic adjustment of the systems of the flame neutralizer and a successful design of its parts one can achieve a stable afterburning of the aldehydes, carbon monoxide and hydrocarbons present in the exhaust gases. However, this is not an easy problem to deal with.

Its solution requires the use of complex, fast-response automatic systems providing for a stable combustion of the extra fuel in the pulsating flow of exhaust gases with $\alpha>1$ for all the operating conditions of the engine.

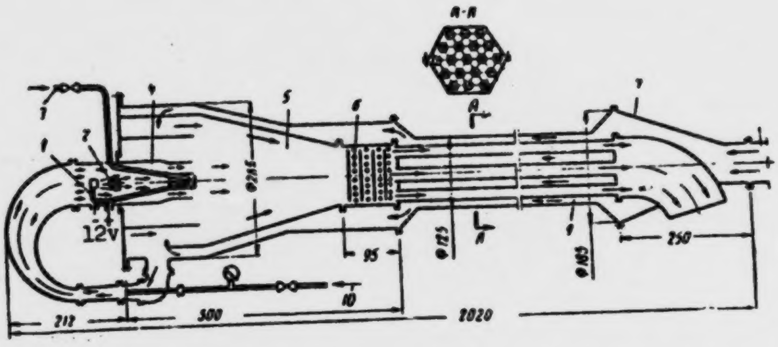


Fig. 35. Diagram of flame neutralizer of exhaust gases from diesel engine of MAZ-205 dump truck (designed by the Ural Scientific Research and Design Institute for the Copper Industry): 1 - vaporizer; 2 - spark plug; 3 - diesel fuel supply; 4 - burner; 5 - combustion chamber; 6 - catalyst (copper); 7 - intake-exhaust nozzle; 8 - intake of exhaust gases from engine; 9 - regenerator; 10 - supply of compressed air from automobile compressor.

The chief drawbacks of flame neutralizers are:

Insensitivity to nitrogen oxides. Moreover, the presence of an additional flame source occasionally also creates an additional source of formation of nitrogen oxides;

Poor neutralization of soot;

Increase in the content of all toxic products of incomplete combustion in the exhaust gases when the operating conditions of the burner deviate from the rated conditions.

Additional consumption of fuel: in carburetor engines under certain conditions, and in diesel engines invariably. This consumption may reach large amounts and exceed several times the fuel consumption required for the operation of the engine (for no-load operation);

High temperatures of the neutralizer parts and units, necessitating the use of heat-resisting steels and excluding the possibility of using flame neutralizers in spaces where an explosion hazard exists;

Instability of operation during changes of the load on the engine because of flame blowoffs;

Need for automation, a separate fuel supply system, and an air supply system to sustain a stable flame.

The use of flame neutralizers does not hold much promise.

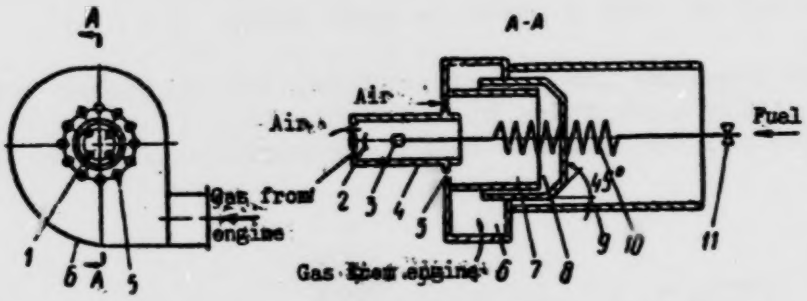


Fig. 36. Diagram of flame ejection-vortex neutralizer (designed by the Ural Scientific Research and Design Institute for the Copper Industry) of exhaust gases of MAZ-525 dump truck:
1 and 5 - openings; 2 - reflectors; 3 - jet tube; 4 - shell; 6 - snail; 7 - combustion chamber; 8 - radial clearance; 9 - housing; 10 - heater; 11 - valve.

3. Catalytic Neutralization of Exhaust Gases

As we know, the rate of chemical reactions, including oxidation and reduction reactions that take place during neutralization of exhaust gases, can be increased several tens and even hundreds of times if they are carried out in the presence of a catalyst, i. e., a substance reacting with the initial product and forming with it intermediate compounds which decompose to yield the end products and the catalyst. Thus, although the chain of reactions proceeds via the catalyst, the latter is not consumed. This principle underlies the operation of catalytic neutralizers.

The exhaust gases pass through a unit filled with a catalyst. In the presence of the latter, the unburned components rapidly oxidize to the final oxides. Nitrogen oxides can be reduced to nitrogen and oxygen on special catalysts. If the neutralizer is designed for carburetor engines, the gases are first diluted with air.

Research aimed at creating catalytic neutralizers has proceeded mainly along the lines of seeking a catalyst which would meet the requirements of use in an automobile, i. e., capable of operating in the gas temperature range from 100 to 900°C, mechanically strong, not poisoned by the components of the exhaust gases, and catalyzing the detoxication reactions of most toxic components of exhaust gases.

The theory of catalysis does not as yet permit a purely theoretical selection of a suitable catalyst for a given reaction under given reaction conditions. The selection is usually made experimentally.

A large number of catalysts were tested with exhaust gases. Pure metals, their oxides and other materials were employed. The best results were obtained with platinum.

Platinum was initially used in the pure form, then experiments were started with thin films of platinum on a porous refractory support (consisting mostly of aluminum oxide Al_2O_3). It was found to be an efficient catalyst for the oxidation reactions of carbon monoxide, aldehydes, and hydrocarbons. At temperatures of the order of 300°C, platinum also has a catalytic effect on reduction reactions of nitrogen oxides. All lead compounds are catalytic poisons for pure platinum, i.e., inactivate the catalyst. Thus, if there are no special recommendations in the operating instructions, catalytic neutralizers with platinum elements are categorically excluded for use with engines operating on ethyl gasoline.

Considerable research on the development of catalytic neutralizers has been carried out by the French company Oxy-France, which has patented many designs. One of its series SB models for carburetor engines of 1 to 150 hp (Fig. 37) consists of one or two welded housings connected in parallel, packed with rod-shaped catalytic elements ("oxycates") of irregular cross section.

The labeling of the neutralizers is as follows: the letters SB indicate that the neutralizer is designed for carburetor engines; the number following the letters indicates the quantity of catalytic elements. To check the operation of the neutralizer, a thermocouple is installed at its exit and connected to an indicator dial in the driver cab, showing the temperature of the exhaust gases.

The neutralizer can be installed in the automobile in any position. At the same time, it acts as a muffler. The guaranteed service life of the catalytic rods is 2500 hrs. The company claims good performance characteristics of the neutralizers.

Data on the operation of a warm SB-4 neutralizer installed in place of a muffler in a new adjusted carburetor engine of 25 hp at 2500 rpm are listed in Table 11.

LANE has developed its own neutralizer designs for the various brands of domestic automobiles. The technology of fabrication of porous supports and their coating with platinum was developed by the L. Ya. Karpov Physicochemical Institute.

The catalytic elements are used in two forms: tubules and beads.

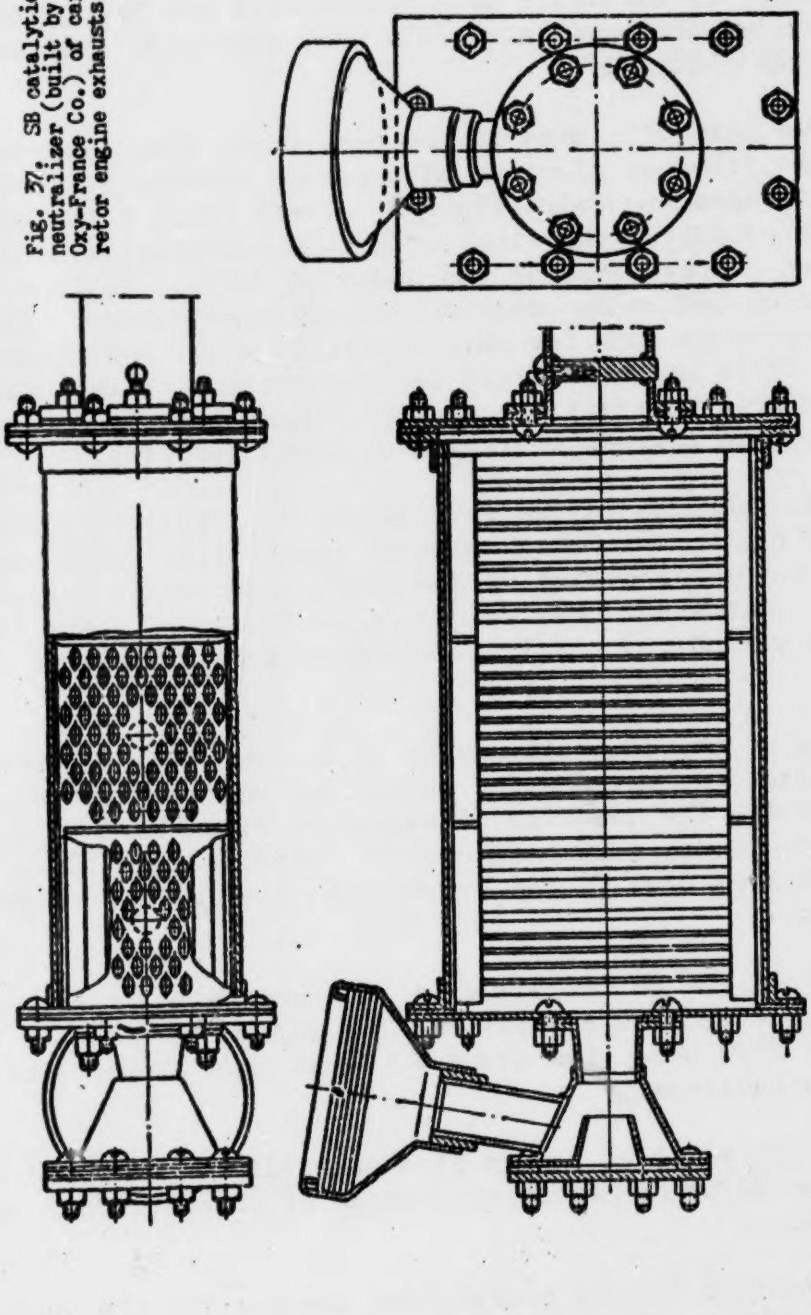


Fig. 37. SB catalytic neutralizer (built by Oxy-France Co.) of carburetor engine exhausts.

Table 11

Rotational Speed of Crankshaft, rpm	Load, %	Engine Power hp	Gas Temperature, °C		CO Content, % by Volume		Degree of Purification, %
			Before Neutralizer	After Neutralizer	Before Neutralizer	After Neutralizer	
500	0,0	0,0	190	370	10,0	0,04	99,6
2500	100	25,4	590	610	4,0	0,02	99,5
2500	75	19,0	600	430	0,15	0,001	99,3
2500	50	12,7	515	370	0,25	0,001	99,6
1500	100	14,6	500	620	7,0	0,02	99,7
1500	75	11,0	510	370	0,1	0,001	99,0
1500	50	7,27	410	300	0,125	0,001	99,2
2800	0,0	4,34	150	350	0,2	0,001	99,5

Tubules are mounted on fine wires (if damaged, the element remains on the wire and does not lose its efficiency), and beads are poured into cartridges. The consumption of platinum per kg of catalytic elements is 4 g for the tubules and 2 g for the beads.

The neutralizers are labeled KNT or KNG - catalytic neutralizer of exhaust gases of carburetor engines with tubular or granular (spherical) elements. The letters are followed by an indication of the flow rate of the gas (nm^3/hr) neutralized by the given model.

In the latest models of neutralizers with spherical elements, the numbers have been used to denote the power of the engine for which the neutralizer is designed, and the letters were changed to NK. Fig. 38 shows a general view of an NK neutralizer.

Bench and running tests of the neutralizers, performed on domestic carburetor engines and automobiles, showed that they:

achieve a practically complete removal of carbon monoxide from the exhaust gases under all the operating conditions of a warm engine;

partly remove nitrogen oxides from the exhausts, and in some cases as much as 50%;

afterburn 80-90% of the hydrocarbons present in the engine exhausts.

The data cited refer to the operation of a warm neutralizer.

If the neutralizer is cooled, and the engine is idling, i. e., characterized by a relatively low temperature of the exhaust gases, the efficiency of the neutralizer when the engine is started and during the initial warmup is practically nil.

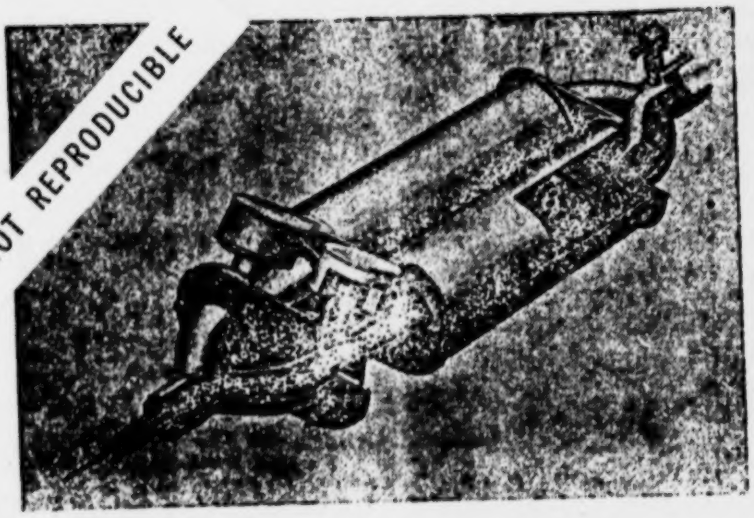


Fig. 38. NK catalytic neutralizer (designed by LANE) of carburetor engine exhausts.

The warmup time of the neutralizer before the start of efficient operation and after the engine has been started at an ambient air temperature of 15-20 C, and when the engine operates at a load of 10-15% of the maximum, is 5-10 min. Warmup during idling can be achieved by intermittently racing the engine.

After the warmup, the neutralizer operates efficiently regardless of the operating conditions of the engine or temperature of its exhaust gases.

When the engine is idling, the temperature in the zone of chemical reactions which is required for an efficient operation is sustained by the heat evolved by the oxidation of unburned components of the fuel.

The effect of installing a neutralizer on the dynamic and economic characteristics of an automobile was also checked. The dynamic characteristics of the automobile remain virtually unchanged, and the economy at speeds in excess of 70 km/hr decreases by about 1.5% (the check was made on the GAZ-21 "Volga" automobile).

Catalytic neutralizers have also been constructed for diesel engines. They differ from the designs of neutralizers for carburetor engine exhausts in the absence in the former of devices supplying extra air for the oxidation of the unburned component. These units are labeled as follows: KNDT, KNDG - catalytic neutralizer of diesel engine exhausts with tubular or granular (spherical) elements. Recently, the labeling was changed to the letters NKD. Only the spherical catalyst is used. Fig. 39 shows the design of an NKD neutralizer.

NOT REPRODUCIBLE

Fig. 39. NKD catalytic neutralizer (designed by LANE) of diesel engine exhausts.

Experience in the operation of catalytic neutralizers shows that they perform efficiently only at exhaust temperatures of 225°C and above. As a result of this temperature limit, the warmup time of a cold unit, even in four-stroke diesel engines, may be as long as 25 min (longer in two-stroke engines).

Because of the low carbon monoxide content of exhaust gases, the necessary temperature conditions of a warm neutralizer are not automatically maintained when the engine is idling or operates at small loads, as in the case of carburetor engines. This limits the time of allowed idling of a diesel engine and of its operation at the small loads following larger loads, i. e., the time during which an efficient neutralization of the toxic components of exhaust gases is maintained, to 5-10 min.

An efficient operation of the catalytic neutralizer during idling and at part loads on the engine can be achieved by preheating the exhaust gases before they enter the neutralizer. Electric preheating is technically feasible.

A system including electric preheating was developed at LANE. Results of its testing with a two-stroke YaAZ-204V diesel engine showed that an efficient operation of the neutralizer under all operating conditions of the engine is achieved by expending 12.2 kW of power (the temperature of the exhaust gases is then raised by 60-70°C, being dependent on the rotational speed of the crankshaft).

However, such a system is very cumbersome and can be recommended only for transport power plants equipped with an electric generator of sufficient output. In particular, it was used for neutralizing the exhaust gases of a YaAZ-204V diesel engine installed as the main engine of a VS-15 diesel-electric self-propelled car designed by the State Experimental Institute of Design and Construction for the Coal-Machinery Industry.

The temperature of the exhaust gases can also be raised by increasing the exhaust counterpressure. Results of experiments at LANE performed on a YaAZ-204V idling diesel engine with a gate valve mounted in front of the neutralizer showed that an increase of the counterpressure to 1.44 kg/cm^2 ensures an efficient operation of the neutralizer even during idling, since the temperature of the exhaust gases rises to 250°C and higher (Fig. 40). However, the development of an additional exhaust counterpressure causes a large increase of the smoke content. This is not observed in four-stroke diesel engines. A check of the degree of temperature elevation of the exhaust gases caused by an increase of counterpressure showed that an effective operation of the neutralizer during idling can be obtained at a counterpressure of 5000-5700 mm H_2O. At LANE, positive results were obtained with a method whereby the temperature of the gases was raised by feeding a portion of them into the intake manifold.

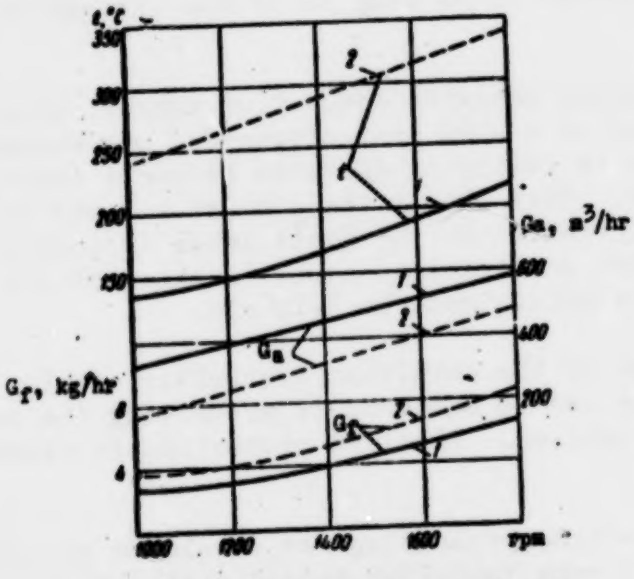


Fig. 40. Dependence of temperature t of the exhaust gases, flow rates of air G_a and Fuel G_f of YaAZ-204V engine on the exhaust resistance:
1 - with gate valve open; 2 - with gate valve closed.

It should be noted that the use of these methods is restricted, since an increase of exhaust counterpressure and by-passing of the exhaust result in an increase of the fuel consumption, a decrease of the coefficient of admission, and a number of other undesirable consequences. The method does not constitute a solution to the problem.

In neutralizers for diesel engines, particularly two-stroke engines, contamination of the catalytic elements with soot, tars, coke, and oil droplets is possible, causing their operational failure. The catalysts are regenerated by roasting in a furnace or by using a welding-torch flame at a temperature of 500°C.

In order to eliminate these disadvantages, catalytic elements have recently been used which operate in the so-called "boiling" bed (also called fluidized, suspended, and turbulent bed), widely employed in the metallurgical, chemical, petroleum and other industries.

In essence, the new method consists in transforming a catalyst bed by a stream of gas to a suspended state in which its individual particles are in random motion. The entire mass of material behaves like a boiling fulid. There is not even any separation of the individual particles of different size and weight, i. e., the light particles do not rise in the bed, and the heavy ones do not descend.

Owing to this vigorous motion of the catalytic elements, the formation of scale on their surfaces is prevented, and they clean themselves. Moreover, the rate of the exchange between the gas and the catalyst increases. There is a considerable (fivefold or greater) decrease in the hydraulic resistance of the bed as compared to that observed in a stationary bed of the same thickness. This decreases the power loss of the engine and reduces the soot content of its exhaust gases.

A disadvantage of the operation of a catalyst in a fluidized bed is its increased wear. However, this disadvantage can be eliminated by using a catalyst of increased mechanical strength.

A fluidized catalyst bed was first used in engine exhaust neutralizers by the staff of the Sverdlovsk Mining Institute.

In 1962, the leading manufacturer of catalytic neutralizers, the French company Oxy-France, began the production of series DN units operating with a fluidized bed catalyst.

Fig. 41 shows the design of one of them, the DN-300 model.

The neutralizer can operate only in the horizontal position and consists of three main parts:

The center - a reactor in the form of a rectangular steel housing divided into separate compartments two-thirds filled with spherical catalytic elements 3-5 mm in diameter and closed off with screens on the top and bottom;

A lower housing distributing the exhaust gases over the intake screen of the reactor;

An upper housing acting as the gas collector.

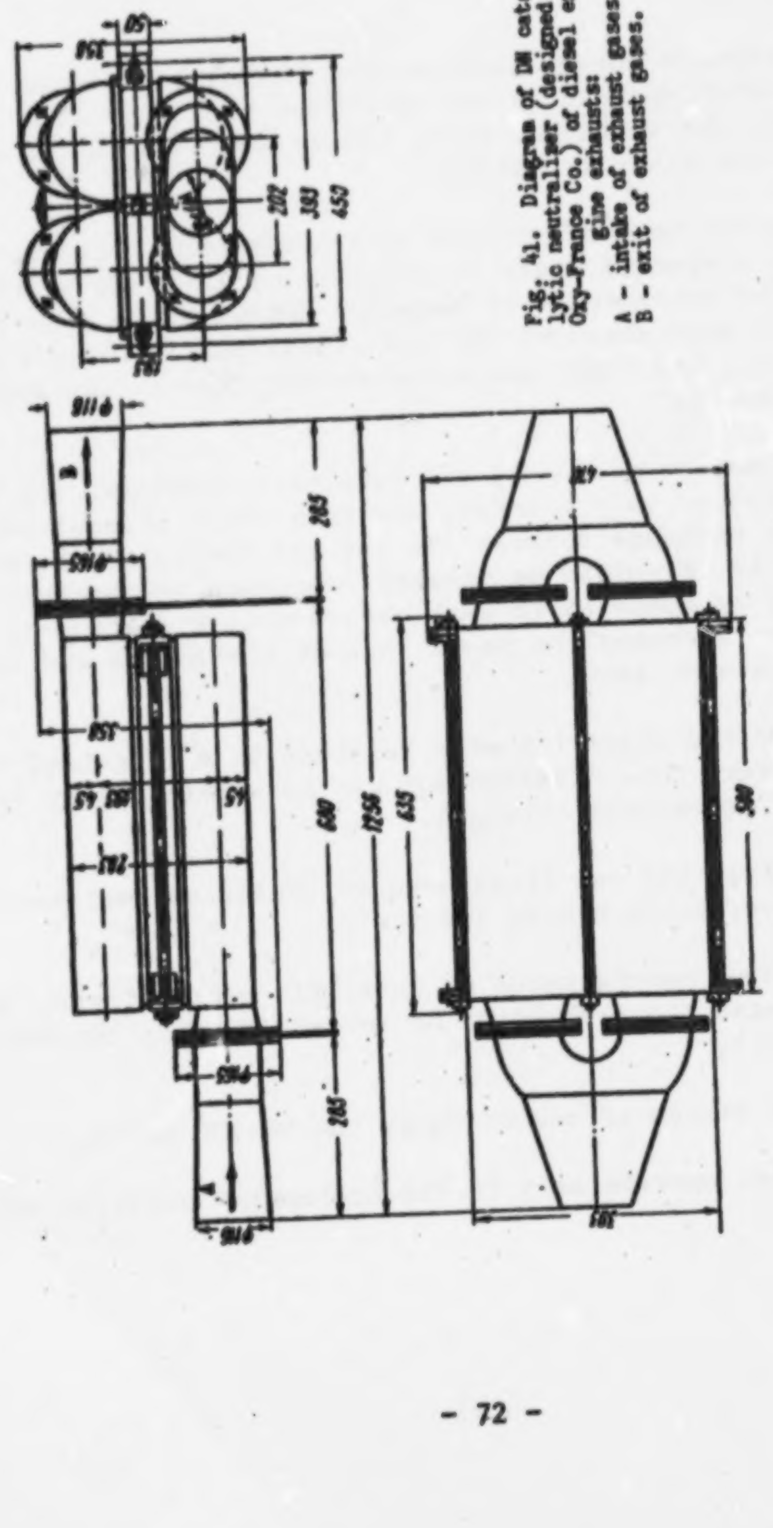


Fig. 41. Diagram of DM catalytic neutraliser (designed by Oxy-France Co.) of diesel engine exhausts:
A - intake of exhaust gases;
B - exit of exhaust gases.

All the parts are joined with yokes. The joints are sealed with asbestos cord of square cross section placed in special grooves.

The company manufactures neutralizers operating with a fluidized bed catalyst and neutralizers for carburetor engines. They are labeled with indices NE. Some of these designs are in vertical versions.

According to the French data, when the neutralizers under consideration operate with engines in sound condition, they achieve the following total neutralization of toxic components of exhaust gases: series NE from 80 to 90%, and series DN from 70 to 85%.

In the Soviet Union, a DN-200 neutralizer was tested on an YaMZ-236 four-stroke diesel engine. The tests showed that:

At engine loads greater than 50% of maximum load, there is a removal of all aldehydes and 70-80% carbon monoxide from the exhaust gases, and the carbon monoxide content of the gases past the neutralizer does not exceed 0.03% by volume at all rotational speeds of the crankshaft;

In the load range from 25 to 50% of maximum load, there is a 50-60% removal of aldehydes and 35-50% removal of carbon monoxide from the exhaust gases; the concentration of aldehydes in the gases past the neutralizer does not exceed 0.011 mg/l, and that of carbon monoxide, 0.026% by volume;

At loads of the cool engine from idling to 25% of maximum load, there is practically no neutralization of the exhaust gases.

LANE also has developed designs of neutralizers with catalytic elements operating in a fluidized bed. The labeling KNDSh was adoped for these models.

Numerous institutes (Karpov Physicochemical Instititе, Institute of Chemical Sciences of the Kazakh Academy of Sciences, and others) are continuing research on the development of a cheaper catalyst capable of replacing platinum.

Fig. 42 illustrates curves showing the change of the carbon monoxide content of exhaust gases from a "Moskvich-407" engine, after they have passed through neutralizers filled with platinum or recently developed nonplatinum elements, as a function of the power developed by the engine. The curves pertain to crankshaft speeds of 1000, 1500, 2000 and 2500 rpm.

The tests were made on an NK-150 neutralizer developed by LANE and differing from earlier designs in the oval shapes of the housing and reactors. This was done for the purpose of more conveniently fitting the neutralizer to the automobile. The weight of the equipped neutralizer was 6 kg, and the outside dimensions were 646 x 252 x 163 mm. A volume of 1.34 l of catalytic elements was poured into the reactor.

The curves of the graphs make it possible to compare the performance of neutralizers with platinum and nonplatinum elements. The comparison shows that only under conditions corresponding to a crankshaft rotating at 1000 rpm is the efficiency of operation of nonplatinum catalytic elements markedly below that of the platinum ones. This is explained by the fact that the minimum temperature of efficient operation of nonplatinum elements is higher than that of platinum elements, and the conditions at n = 1000 rpm correspond to relatively low exhaust temperatures.

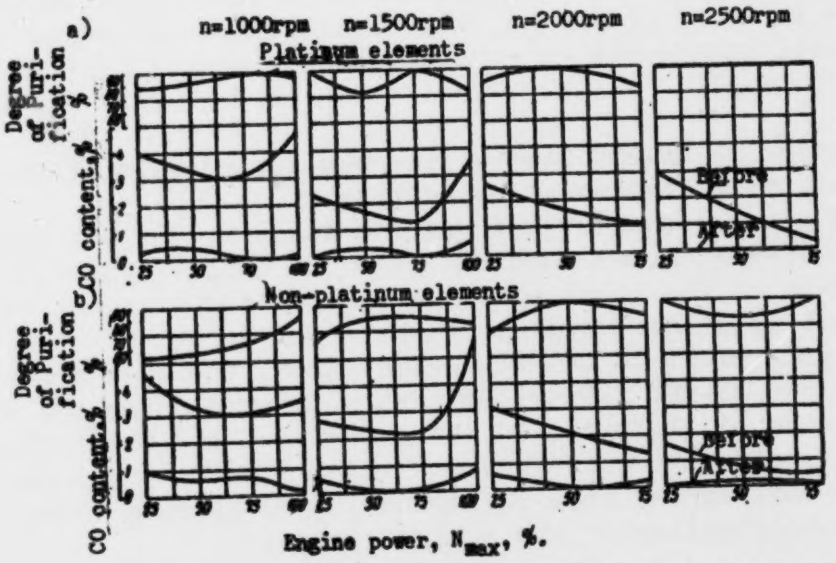


Fig. 42. Graph of change of carbon monoxide content in exhaust gases of "Moskvich-407" engine after passage through NK-150 catalytic neutralizer.

The average efficiency of neutralization under the indicated conditions ranges from 80% to a virtually complete neutralization for the alumina-platinum catalyst, and from 65% to a virtually complete neutralization for the non-platinum catalyst. Thus, the new elements can sucessfully replace platinum ones. Tests of units with the new elements are being continued.

For the low exhaust temperatures observed in diesel engines, LANE tested hopcalite (a mixture of 60% active manganese dioxide MnO_2 and 40% copper oxide CuO) as the catalyst under laboratory conditions. The experiments showed that it neutralizes carbon monoxide very well under all operating conditions of the diesel engine, but is marked by a low mechanical strength. Ways of increasing its strength are being sought. Hopcalite was used in a combined neutralizer of exhaust gases of an YaAZ-204V diesel engine installed on a VS-15 diesel-electric car. The combined neutralizer consists of two units: a liquid unit and a low temperature catalytic unit filled with hopcalite. This neutralizer was discussed in §1 of this chapter.

4. Thermocatalytic Neutralization Of Exhaust Gases

The chief disadvantage of a catalytic neutralizer is that it operates efficiently starting at a certain temperature of the exhaust gases (225°C). It is natural therefore to try to develop a composite design of the unit, in which the gases would first be preheated in a flame afterburner, resulting in a partial afterburning of the unburned toxic components, and would finally be neutralized on the catalyst.

Neutralizers operating on this principle have been named thermocatalytic neutralizers. Their development was started at the Sverdlovsk Mining Institute. One of its designs, intended for the neutralization of exhaust gases of a D12A diesel engine installed on an MAZ-525 dump truck, is illustrated in Fig. 43.

The neutralizer consists of two units connected in series - flame preheater of gases 4 and catalytic neutralizer 6. Burner 5 without a nozzle generates a flame in the preheater. When passing over spiral conduit 1 of the preheater, the fuel vaporizes and enters the combustion chamber while being vigorously mixed with the air supplied by fan 3, which is driven independently. The fuel-air mixture is ignited either by the heated spiral of plug 2, or by the flame front under steady combustion conditions.

The combustion in the chamber has an autonomous course that is independent of the operating conditions of the engine; and thus a steady combustion is achieved. When the engine runs at large loads, in order to economize the fuel and keep the unit from overheating, the fuel supply to the chamber is automatically shut off.

The preheated gas enters cyclone 7, attached to the outer wall of reaction chamber 9. Here the fine solid and liquid particles of soot, tars, oil, etc., which earlier had not burned completely, undergo the final stage of combustion. The coarse particles are thrown against the walls and are collected in hopper 11. The cyclone also recovers the heat evolved by the catalytic oxidation processes. The exhaust gases, warmed up and purified after the removal of the solid and liquid particles that they contained, enter reaction chamber 12 of the catalytic neutralizer.

Here they traverse the catalyst beds: lower fluidized bed 10 and upper 8, which is at rest. The purpose of the lower bed is to neutralize a large portion of the toxic components. The upper bed completes the neutralization process and prevents the escape of fine catalyst particles from bed 10.

Tests of the above neutralizer demonstrated its stable operation and, when an active catalyst was used, a satisfactory neutralization of the toxic products of incomplete fuel combustion. The hydraulic resistance of the neutralizer slightly exceeded the resistance of a standard muffler.

The neutralizer simultaneously acted as a noise muffler.

Designs of thermocatalytic neutralizers are being developed in which the combustion is arranged directly in the flow of exhaust gases, with the oxygen present in the aerosol used as the oxidant. Composite neutralizers with nozzle burners, with trapping of soot in a special filter that simultaneously burns it up, etc., also are being worked on.

The chief drawbacks hindering the adoption of thermocatalytic and composite neutralizers in automobiles are as follows:

Complexity of design;
Necessity of additional consumption of fuel;
High temperatures of certain parts;
Large consumption of catalyst operating in the fluidized bed because of its low mechanical strength;
Large weight and overall size.

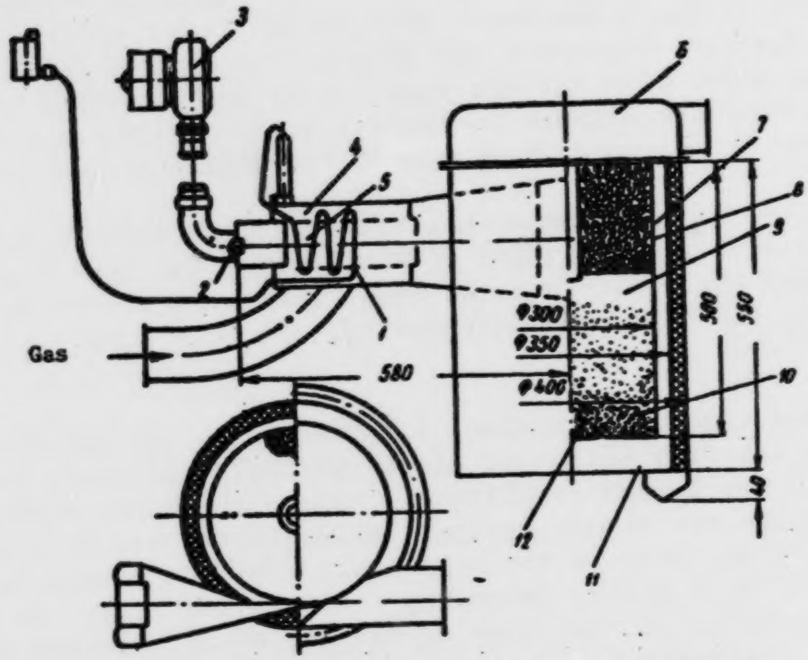


Fig. 43. Thermocatalytic neutralizer (designed by Sverdlovsk Mining Institute) for exhaust gases of D12A diesel engine.

5. Electric And Ultrasonic Filters

The principle of operation of electric filters consists in the electrolysis of the solid and liquid particles present in the gases in suspension, followed by their deposition on the electrodes. This method has been fairly popular in industrial gas purification. In practical detoxication of exhaust gases, electric filters are seldom used, since their efficient operation requires cumbersome gas coolers by means of which the toxic components are converted to the liquid and solid states.

In 1961, a neutralizer operating in the following manner was developed and tested in Switzerland. First, the exhaust gases were cooled in a special cooler to 30°C. Some toxic components such as a portion of the hydrocarbons, acrolein, and many of others deposited on the walls of the cooling chamber. The gas then entered the electric filter. In its ionizing compartment, the particles suspended in the gas interacted with ions of oxygen, nitrogen and other gaseous components, an electric charge was produced, and the particles were directed into the trapping compartment, where they deposited on the electrodes in a high-voltage electric field.

According to the statements of the authors of this invention, for a consumption of 15 W of power, the filter completely trapped soot and other solid particles, there being a very low hydraulic resistance. After 500 hrs of operation, the filter required washing and drying.

Lately, the industrial use of ultrasound has been increasing. In particular, it is used to remove noxious impurities from furnace fumes. Ultrasonic waves cause a rapid vibration of the solid particles suspended in the gas, causing their agglomeration, coarsening, and hence, an easy trapping. Thus far, ultrasound has found no direct applications in the neutralization of engine exhausts. However, there are very good reasons to assume that it can be used, if not directly for the purification of gases, then at least for the acceleration of certain processes associated with purification. For example, in liquid neutralizers, ultrasound can be used for speeding up the chemical dissolution of toxic gas components, coarsenging solid particles in solution to make them settle faster to the bottom, and preventing their escape with gases.

6. Crankcase Gases And Control Of Their Toxicity

With the exception of the intake stroke, the pressure in the crankcase is much lower than in the engine cylinders. As a result, part of the fuel-air mixture and exhaust gases escape through various leaks from the combustion chamber into the crankcase. These gases mixed with oil and fuel vapors are called crankcase gases.

The gases escaping from the cylinders consist, on the average, of 80% of the fuel-air mixture and 20% of exhaust gases. This composition is explained by the fact that the seeping of gases from the cylinder takes place chiefly at high pressures in the combustion chamber, i. e., at the end of compression during combustion and at the start of expansion. Moreover, additional conditions favoring the escape of gases are produced when there is a change in the direction of motion of the piston in the extreme upper position, when the piston rings shift in the grooves. In a new engine, gas leaks are slight, but they gradually increase as the engine is used.

The adverse effect of crankcase gases is that they dilute the crankcase oil, increase the explosion hazard, are the chief source of water formation in the crankcase, and decrease the useful life of the oil by contaminating it and raising the acidity. The crankcase gases together with the exhaust gases poison the atmosphere when released. It has been found that crankcase gases account for about 40% of the total hydrocarbons emitted by automobile engines.

Forced ventilation of the crankcase has long been used in the automobile industry as the chief method of controlling the adverse effect of crankcase gases. The main requirement of this method is as follows: the gases must be eliminated before their temperature drops to a value at which the fuel and water vapors which they contain begin to condense and descend into the oil.

The gases can be sucked out by creating a vacuum in the intake system of the engine and by utilizing the fluid energy of the fuel-air mixture. Accordingly, the following three systems of forced crankcase ventilation are used, involving suction of gases into:

the air filter;
the intake manifold (past the carburetor);
the air filter and the intake manifold.

The graph (Fig. 44) showing the operation of the system of suction of crankcase gases into the air filter shows that as the speed of the automobile rises, there is an increase in the escape of gases into the crankcase (curve 4) and in the amount of air entering the air filter from the crankcase (curve 1). However, during idling and at small loads, the crankcase ventilation is insufficient in this system. Here the crankcase gases will escape into the atmosphere through the oil hole.

This disadvantage is eliminated in a system where the gases enter the intake manifold. A graph of its operation (Fig. 45) shows that during idling and at small loads, an adequate ventilation of the crankcase is achieved (curve 1). However, at large loads on the engine, when the amount of crankcase gases increases (curve 3), the momentum of the jet of the fuel-air mixture is insufficient for the suction of all the gases. A portion of them escapes into the atmosphere through the oil holes.

The combination of the two systems makes it possible to achieve the suction of crankcase gases under all operating conditions of the engine.

In practice, the suction systems are connected to each other with a control valve in-between which prevents the gases from entering the intake manifold from the air filter. Thus, the crankcase is ventilated by a system connecting it to the intake manifold, but under all conditions of large loads this system is connected to the system in which the crankcase is vented into the air filter.

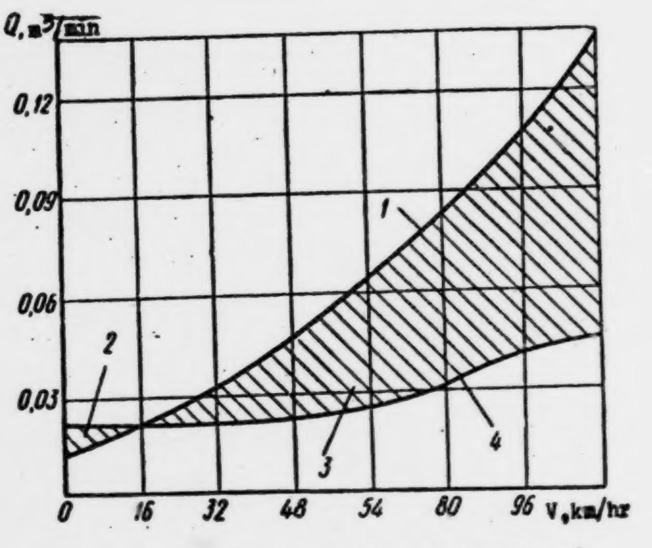


Fig. 44. Graph of the operation of a system of gas suction from crankcase into air filter:
1 - admission of total amount of crankcase gases and air into air filter vs. traveling speed of automobile; 2 - amount of crankcase gases escaping through oil hole; 3 - amount of fresh air entering the air filter; 4 - emission of crankcase gases vs. the traveling speed of automobile.

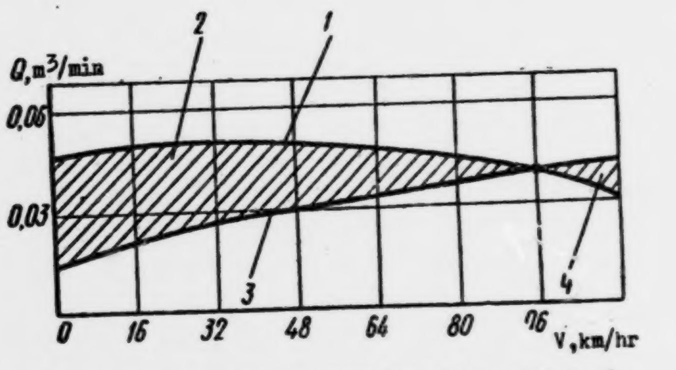


Fig. 45. Graph of the operation of the system of suction of gases from the crankcase into the intake manifold:
1 - admission of the total amount of crankcase gases and air into the intake manifold vs. traveling speed of automobile; 2 - amount of fresh air entering the intake manifold; 3 - emission of crankcase gases vs. traveling speed of the automobile; 4 - amount of crankcase gases escaping through oil hole.

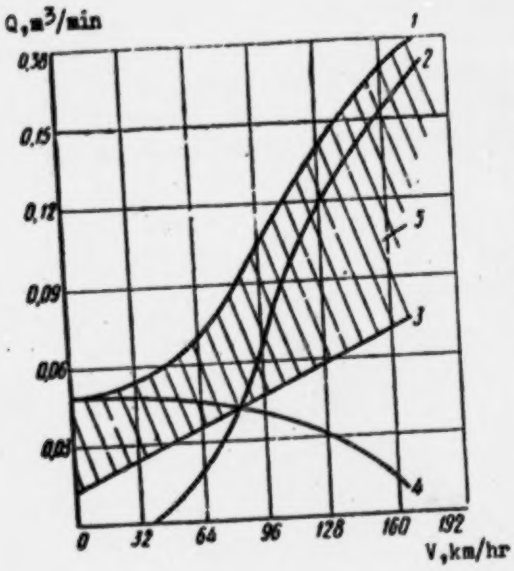


Fig. 46. Operation of combined system of gas suction from the crankcase into the air filter and into the intake manifold: 1 - admission of total amount of crankcase gases and air into the air filter and into the intake manifold vs. traveling speed of automobile; 2 - admission of total amount of crankcase gases and air into the air filter along vs. traveling speed of automobile; 3 - emission of crankcase gases vs. traveling speed of automobile; 4 - admission of total amount of crankcase gases and air into the intake manifold alone vs. traveling speed of automobile; 5 - amount of fresh air admitted.

A graph (Fig. 46) of the operation of the composite unit shows its satisfactory operation in all engine runs. Other combined systems also exist. In particular, suction of the crankcase gases into the exit manifold or neutralizer is employed.

Chapter V

PROSPECTIVE AUTOMOBILE ENGINES AND EXTENT OF POSSIBLE POISONING OF THE ATMOSPHERE BY THEM

Scientific research laboratories, design organizations, and industrial enterprises in many countries throughout the world are studying and testing improved designs of internal combustion engines as well as fundamentally new energy sources. In addition to the analysis of such indices as power, economy, complexity of construction, cost, etc., considerable attention is given to the degree of possible contamination of the air reservoir by the engines.

All prospective engines can be divided into two major groups: mechanical energy converters whose design is dependent on moving parts, and nonmechanical converters which transform one of the forms of energy (chemical, thermal, nuclear) directly into electrical energy in the absence of parts that rotate or execute a translational motion. The present chapter discusses the diagrams and explains the principles of action of certain improved and new automobile engines being developed. It should not be assumed that sooner or later they will all be adopted in automotive engineering. It is quite possible that some of the experimental designs will never leave the laboratory.

1. Mechanical Energy Converters

Piston-type internal combustion engines. Piston engines are currently the main transport engines. One of the ways of radically improving them which will reduce the toxicity of the exhaust gases is to reorganize their working process. This can involve the use of the latest achievements in physics and chemistry. The possibility of using energy sources other than ignition plugs to ignite the working mixture is not excluded. In particular, there are no fundamental objections to the use of laser beams. An efficient ignition and improved atomization of the fuel should increase the extent of combustion and reduce the emission of toxic substances.

Good results can be obtained by developing a laminar distribution of the fuel-air mixture. The process consists essentially in producing a distribution in the combustion chamber whereby a rich-mixture zone is produced only in the vicinity of the ignition source (for example, a plug), and as the distance from this source increases, a lean-mixture zone is formed. In this case, the combustion occurs with a high degree of completeness. The toxicity of the exhaust components being currently standardized decreases. The first test of this arrangement of the process is the creation of prechamber-flame ignition.

To achieve a pollution-free operation of engines, closed and semiclosed cycles have been developed. In the former case, the fuel and the oxidizer are separately supplied to the engine. The combustion products are separated. A portion of them (carbon monoxide, aldehydes, hydrocarbons, etc.) is returned to the cylinders for additional combustion, and another is collected in special cylinders. Similar systems have already been used in the submarines of a number of nations. Their chief disadvantages are bulkiness and a high cost. A basic diagram of a closed cycle system is shown in Fig. 47.

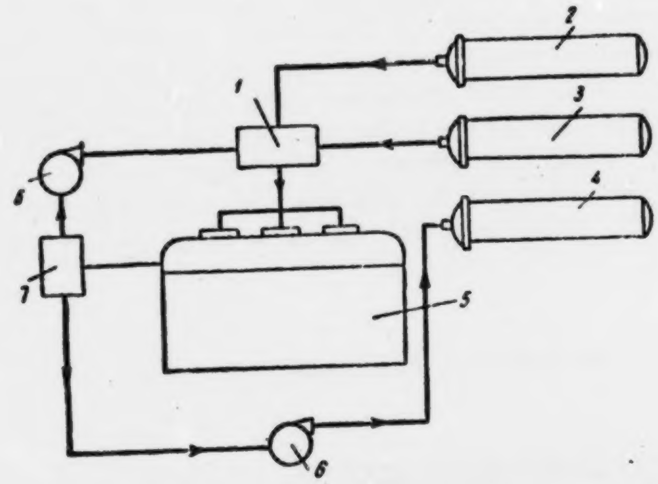


Fig. 47. Basic diagram of system operating on a closed cycle: 1 - mixer; 2 - fuel cylinder; 3 - oxidizer cylinder; 4 - cylinder for end products of combustion; 5 - engine; 6 - pump; 7 - component separator.

For automobile engines, usually operated under conditions where there is no deficiency of oxygen for the combustion of fuel, the above system may be simplified (Fig. 48). In operation on a semiclosed cycle, the oxygen for combustion is taken from the atmosphere: nitrogen, carbon dioxide, and water, which are not harmful to man, are discharged.

The difficulty in building engines operating on closed and semiclosed cycles lies in the development of separators of the exhaust components.

Rotor (volumetric) internal combustion engines. A diagram of the operation of one type of rotor engine with a planetary motion of the rotor is illustrated in Fig. 49. Other types do not differ from this type in operating principle. The working cycles of rotor engines do not differ from those of piston engines. The chief advantage of rotor engines lies in the absence of reciprocating parts, which makes it possible to substantially increase the rotational speed of the shaft and decreases the weight and overall size of the engine.

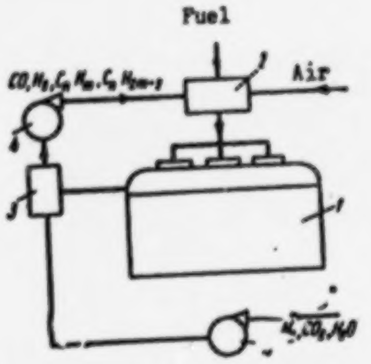


Fig. 48. Basic diagram of a semiclosed cycle system: 1 - engine; 2 - mixer; 3 - component separator; 4 - pump.

Since in rotor engines the rate of change of the volume of its expanding gas can be controlled by means of attachments, this should affect the composition of the exhaust gases. The presence of centrifugal forces in the zone of formation of the working mixture also simplifies the creation of a laminar distribution of the mixture, which should result in a better arrangement of the combustion process and in a reduction of the toxicity of the exhaust gases.

Gas-turbine engines. Some foreign companies are already preparing automobiles powered by gas-turbine engines for production. Experimental models of such automobiles are also being tested in the Soviet Union. In automobile construction, the engines which have found applications have been mainly in the 200-1000 hp range.

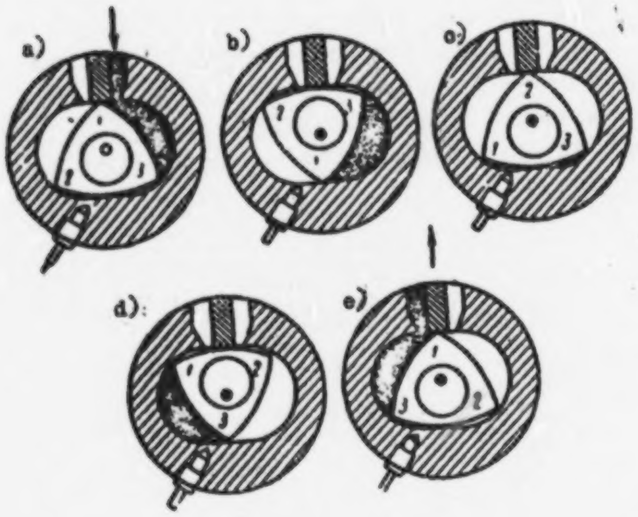


Fig. 49. Diagram of operation of the rotor engine: a - intake; b - compression; c - ignition; d - power stroke (expansion); e - exhaust.

The specific weight of a modern gas-turbine engine (weight per unit power) and its size are smaller than those of piston engines, but the cost of a gas turbine engine is higher. From the standpoint of reduction of the toxicity of exhaust gases, the gas-turbine engines are more acceptable than piston engines with regard to the components being standardized at the present time. Such engines can operate stably on lean mixtures, which have lower combustion temperatures. This reduces the content of carbon monoxide, soot hydrocarbons and other toxic compounds in the exhaust gases, with the exception of nitrogen oxides.

Jet engines. Regardless of the type of jet engine, they all operate on the same principle: hot gases are ejected from nozzles into the atmosphere at a high velocity. This produces a thrust which increases with the amount of gases ejected and with the ejection velocity.

The motive power acts directly on the automobile, so it is no longer necessary to transmit the tractive effort from the engine to the wheels. As a result, the force moving the automobile is independent of the friction between the tires and the road surface. This is an obvious advantage of the jet engines.

However, the fact that a powerful gas flow is required to produce a sufficient moving force cancels out this advantage. The overall size and weight of the jet assembly turn out to be very large. The high ejection velocity of the gases is not permissible from the standpoint of traffic safety considerations.

Stirling engine. In 1816, the Scottish clergyman Robert Stirling invented a new external combustion piston engine. It was characterized by a very large overall size and a low efficiency. Improvement of the engine proceed at a very slow pace. In 1855, the Stirling engine had an efficiency of 5-7%, power of 2 hp, weight of 4 tons, and occupied 21 m^3 of space. It seemed as though it would never be developed. However, starting in 1937, interest in this engine was reawakened, first in Holland and later in the USA.

Recent studies of the engine made by the General Motors Co. showed that:

The efficiency of the engine can reach 50%, which is far above the efficiency of gas turbines (25-28%), best models of carburetor engines, (28-30%) and best models of diesel engines (32-40%), but the specific weight of this engine is higher than that of the other engines;

The engine operates satisfactorily at constant loads, but the rotational speed of its shaft has thus far been moderate;

The engine operates without noise on different fuels: solid, liquid, and gaseous.

The engine can be made to work without poisoning the atmosphere with exhaust gases.

The engine has a working piston 1 (Fig. 50) and a displacing piston 4, both located in the same cylinder.

The piston rods are located one within the other and connected to a crankgear. The upper part of the cylinder is steadily heated by any suitable heat source (combustion chamber with solid, liquid or gaseous fuel, electric heater, etc.), while the lower part is steadily cooled by a cooler 2. Accordingly, the space within the cylinder is divided into two cavities: one hot 5, and the other cool 3; heat exchanger 6 increases the economy of operation of the engine, and cavity 7 acts as a buffer.

The engine operates in the following manner:

Stroke I - cooling. The displacing piston is located in the hot space, and the working piston is in its lowest position. Much of the gas is cooled in the cold cavity;

Stroke II - compression. The working piston moves upward, compressing the cool gas;

Stroke III - heating. The displacing piston moves downard. The cool gas is transferred to the space above it, being first warmed up in the heat exchanger. The gas is heated in the hot cavity;

Stroke IV - expansion (working stroke). The hot gas expands, doing useful work, while at the same time heating the heat exchanger. The working piston, by transferring the gas located under it into the buffer cavity and compressing it, stores up energy for the next compression of the working gas.

At a symposium of engine specialists held in the USA in October 1963 it was noted that the Stirling engine will not find any rapid practical applications in automotive engineering, since it has a number of essential disadvantages. However, its use in the automobile has not been excluded.

Since the heating of the hot cavity takes place on the outside and is not directly connected with the course of the working process within the cylinder, it becomes possible to ensure the combustion of any hydrocarbon fuel with a minimum ejection of toxic substances.

2. Nonmechanical Energy Converters

A radical means of reducing the poisoning of the air reservoirs of cities and industrial plants is to replace automobiles with carburetor and diesel engines by electrically driven vehicles.

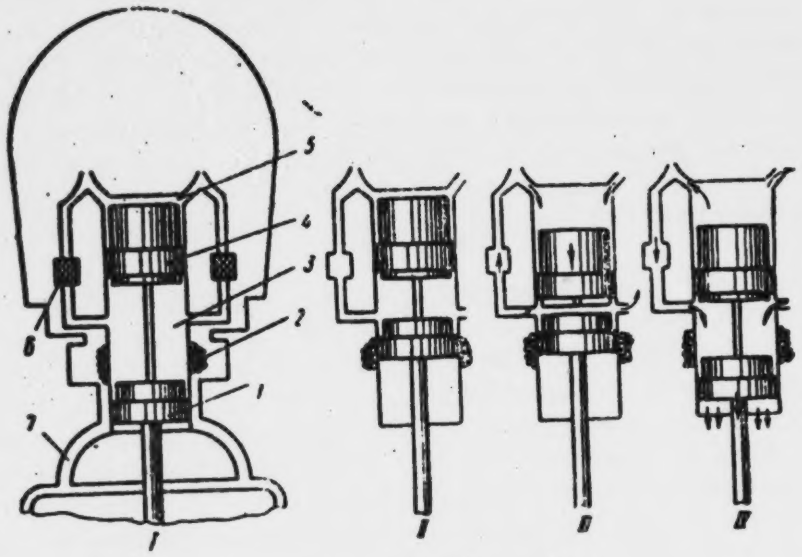


Fig. 50. Diagram of operation of Stirling engine:
1 - working piston; 2 - cooler; 3 - cold cavity; 4 - displacing piston;
5 - hot cavity; 6 - heat exchanger; 7 - buffer cavity; I - cooling;
II - compression; III - heating; IV - working stroke (expansion).

Obviously, electrically driven trolley buses and electric rail transport cannot constitute a serious rival to automobile transportation because of its limited maneuverability and the high capital investment required by the trunk lines.

In the USSR, the first attempts to replace automobiles by electrically driven public transportation vehicles date back to the 1930's, when on the suggestion of the eminent Soviet electrical engineer G. I. Babat, the first studies anywhere on the use of high-frequency wireless transmission of energy to transport vehicles were carried out. Babat's "hf-mobiles" had receiving induction units, and the trunk lines were equipped with high-frequency underground power communications. By storing up excess electrical energy in chemical storage batteries, the hf-mobiles were able on ordinary thoroughfares to switch from one specially equipped line to another. The first high-frequency lines were tested in the USSR in the 1940's. However, for various reasons the hf-mobiles were not widely adopted.

At the present time, the prospects of using electrically powered transportation are chiefly dependent on the development of high-efficiency, self-contained sources of electrical energy. These sources, based on principles of direct conversion of various forms of energy into electrical energy, are commonly called nonmechanical converters. It is understandable that the power plant of an electric car as a whole, equipped with a power source and an electric motor, is not nonmechanical. Nonmechanical converters include physical sources: magnetohydrodynamic, thermoelectric, and thermionic generators, and also chemical energy sources: storage batteries and fuel cells.

Magnetohydrodynamic generators of electric energy (MHD generators). As we know, if a conductor is moved in a magnetic field, an electric current will be induced in it. This is the principle underlying the operation of most modern electric generators. The conductor in motion is not necessarily metallic. It can also be an electroconductive liquid, and even gases. Although gases in the natural state poorly conduct electric current, they can be transformed into good conductors when subjected to ionization. A completely ionized gas, i.e., one in which there are no neutral molecules or atoms, is called a plasma. In order to obtain a plasma, a high gas temperature is required, sometimes as high as millions of degrees. This is very hard to achieve. It is equally difficult to hold it in any conduit, i.e., the walls of the container simply cannot withstand such temperatures.

However, in order to use a gas as the conductor of an electric current, there is no need to convert it to a plasma, since a gas ionization of 0.1% (one out of every 1000 gas molecules is dissociated) is sufficient to produce a conductivity in the gas equal to about one-half that of a plasma. However, even in order to produce a gas with 0.1% ionization, a temperature of the order of 2750°C, is required. This is the chief obstacle to a possible application of MHD generators toautomobiles. The most probable area of application of such generators is a generators of current in high-output electric power plants. The installation of MHD generators in diesel locomotives and tractor-trailer combinations is possible.

A basic diagram of an MHD generator assembly is shown in Fig. 51. Atmospheric air compressed to 5 kg/cm^2 with a compressor is supplied to the combustion chamber through a heat exchanger. From the latter, the mixture of air and combustion products, at a temperature of about 2750°C, which gives a degree of gas ionization of 0.1%, enters the MHD generator through a supersonic nozzle, expanding to an excess pressure of 0.1 kg/cm^2. At this point, a magnetic field acts on the gas. The electric current which is thus produced is picked up by the electrodes bathed by the gas. From the MHD generator, the gases at a temperature of the order of 2000°C are directed into the heat exchanger, then released into the atmosphere. Experimental models of MHD generators operating at lower temperatures have been constructed.

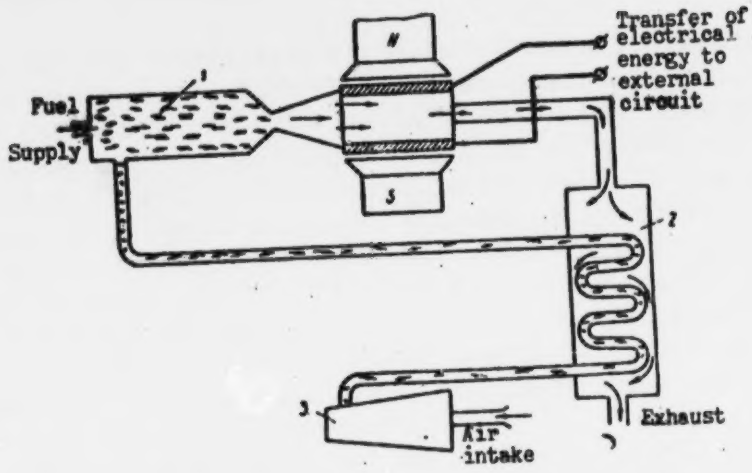


Fig. 51. Diagram of open-cycle MHD generator assembly operating on hydrocarbon fuel:
1 - combustion chamber; 2 - heat exchanger; 3 - compressor.

The toxicity of the gases discharged by such an assembly will probably be similar to that of the exhaust from gas turbines.

Thermoelectric generators of electrical energy. As we know, most metals are good conductors of electricity. This is because, even at room temperature, the metals contain many free electrons whose ordered motion in a given direction constitutes an electric current. If no voltage is applied to a metal rod, the free electrons move in random fashion. If one end of the rod is heated and the other cooled, the electrons in the former will move faster than in the latter. As a result, a preferential motion of electrons from the hot end to the cold will be established, and an electric current will be generated in the rod. This current cannot be picked up by an external circuit if the rod and the conductor are made of the same material. Indeed, an electric current with a direction opposite to that in the rod will also be generated in the conductor with one hot and one cold end. However, if the rod and the conductor are made of different metals with different numbers of free electrons, the rate of their motion from the hot end to the cold will be different, and a slight net current will flow along the closed circuit. This effect was discovered as long ago as 1821. It is used in the manufacture of various thermocouples (the electromotive force generated on heating is proportional to the temperature difference between the hot and cold junctions). The use of the Seebeck effect proved impossible for the creation of high-output power sources. Attempts to connect individual thermocouples in series have been unsuccessful. As the number of the connected couples increases, there is a marked increase in the total electrical resistance of the circuit.

Nevertheless, after a long selection of different materials, a thermoelectric battery with an efficiency of 3% was successfully assembled in 1950.

The situation changed radically with the discovery and development of semiconductors. For the same temperature difference, a thermoelectromotive force is generated in semiconductors that is 40 times (or more) greater than the thermoelectromotive force in metals. Depending on the nature of conduction, semiconductors are divided into three types: n-type, p-type, and intrinsic semiconductors. n-Type semiconductors contain many free electrons. They are the carriers of negative charges. On the contrary, in p-type semiconductors there is a deficiency of electrons. A crystal lattice site where an atom lacking an electron is located has a positive charge and is called a "positive hole". If the atom borrows an electron from a neighboring atom of the crystal, it becomes neutral, and the atom which has lost the electron becomes the "positive hole". Thus, the "positive hole" effectively moves through the material of the semiconductor, and for this reason p-type semiconductors are frequently called carriers of positive charges. Intrinsic semiconductors are carriers of both negative and positive charges.

By selecting appropriate semiconductors, thermoelectric generators with an efficiency of up to 10% have been successfully constructed.* A basic diagram of one of the generators operating on hydrocarbon fuel is illustrated in Fig. 52.

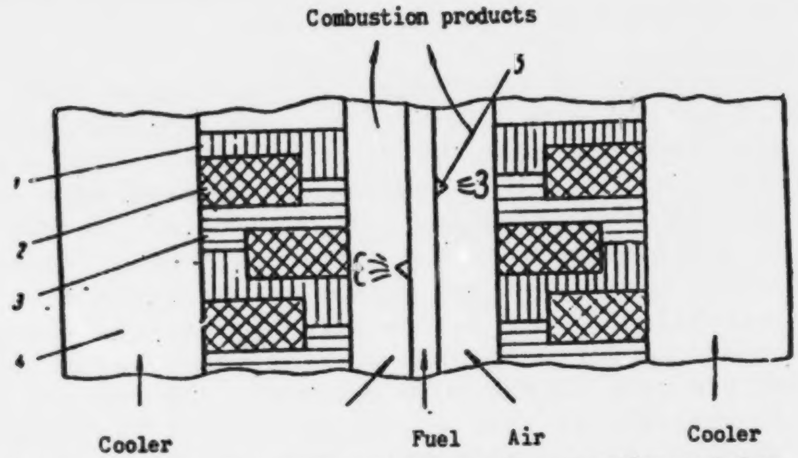


Fig. 52. Diagram of thermoelectric generator operating on hydrocarbon fuel. The heat of escaping combustion products is not used.
1 - p-type semiconductor; 2 - insulator; 3 - n-type semiconductor; 4 - cooler; 5 - injector.

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* This value of the efficiency refers only to the generator. When the generator is used in an automobile, it is necessary to take into account the energy loss in transmission to the wheels.

There are also generators operating on nuclear fuels.

If the heat of the combustion of hydrocarbon fuels is used for heating semiconductors, the toxicity of the emitted products of such units will be the same as in the case of gas-turbine engines.

Thermionic generators of electricl energy. If a metal is heated intensely and placed in a vacuum, part of the free electrons may acquire a considerable energy, overcome the forces of attraction of other molecules, and escape from the metal. This effect is called thermionic emission or, in honor of its discoverer, the Edison effect. The energy required for an electron to break away from the metal surface is called the work function.

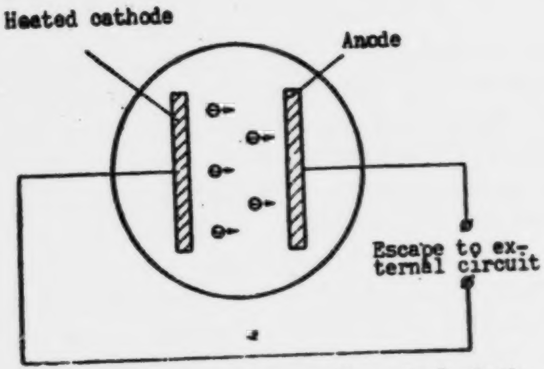

Fig. 53. Diagram of operation of simplest diode radio tube. The same principle governs the operation of the thermoelectronic generator.

The Edison effect is utilized in diode radio tubes (Fig. 53). Two electrodes, a cathode and an anode, are placed in an evacuated bulb (the tube is therefore called a diode). The cathode is heated. The electrons whose energy exceeds the work function of the cathode leave the latter in the direction of the anode. Here they overcome the potential barrier corresponding to the work function of the anode, i.e., give up part of the energy in order to "enter" the material of the anode. This energy is converted to heat which heats the anode. Since the work function of the cathode is usually higher than that of the anode, the excess energy in the form of an electric current is removed by the external circuit. If the radio tube is treated as a thermionic converter of the thermal energy heating the cathode into electrical energy, its efficiency is very low and equal to approximately 0.00001%. This is not very import in radio equipment, where the required current intensity does not exceed a few microamperes.

Thermionic generators, used for the industrial generation of electric power, operate on the same principle. However, their efficiency has now reached approximately 20%. This is accomplished by the following methods:

The cathode material selected has a large work function. The cathode is heated to high temperatures, of the order of 2000-2200°C. Only refractory metals are used (a suitable material is one in which after 1000 hr of operation at the working temperature, the layer thickness due to vaporization decreases by not more than 0.127 mm);

The material chosen for the anode has a small work function. The anode is cooled so that its working temperature is 550-1100°C below the cathode temperature;

The space charge is eliminated and neutralized. Each electron which has escaped from the cathode is surrounded by electrons which have left earlier. The electrons repel one another, and as a result, many electrons return to the cathode without reaching the anode. The charge of the escaped electrons is termed the space charge. To eliminate it, the cathode and anode are placed as close to each other as possible (in 1960, the American company General Electric produced converters with interelectrode distances of 0.0127 mm and less), or an additional electrode is placed between them which imparts a high velocity to the electrons. The space charge is neutralized by introducing into the bulb vapors of cesium, whose molecules readily ionize on colliding with the electrons. A plasma cloud is thus formed which consists of positively charged cesium ions, extends from the cathode to the anode, and neutralizes the space charge.

As in the case of thermoelectric generators, the use of thermionic generators in automobiles is still problematic. However, because they can have higher efficiencies, they should be given priority. Their best prospects are for application in the atomic industry.

From the standpoint of poisoning of the atmosphere, units employing thermionic generators are similar to those with thermoelectric generators.

Electric automobiles with storage batteries. Designs of storage-battery-powered automobiles have been adequately developed. At the present time, there are about 40,000 electric care with lead storage batteries being operated in the world, excluding local electric transport (streetcars and trolleys). The main unit of an electric car is the storage battery.

The characteristics of modern storage batteries are listed in Table 12.

Table 12

Type of Storage Battery	Specific Power for 5-Hour Discharge, W/kg	Specific Energy for 5-Hour Discharge, W hr/kg	Number of Discharge-Charge Cycles	Capacity for Discharge Under Forced Conditions	Cost, Relative Units
Lead	~4	20—25	Up to 1000	Good	1
Iron-nickel	3,5—4	18—20	Up to 1800	Poor	1,2—1,5
Cadmium-nickel, lamellar	4—4,2	18—25	Up to 2000	Satisfactory	4
Cadmium-nickel, sealed, nonlamellar	9—10	25—40	1500—3000	Good	20—25
Silver-cadmium	18—23	60—90	200—300	Satisfactory	5
Silver-zinc	20—25	80—160	300—400	Good	6
Nickel-zinc	10—13	60—70	Up to 200	Good	2—3
Air-zinc	20—30	100—150	No Data	Good	Nc Data

As is evident from the table, the silver-zinc storage batteries, which are the best of the commonly used batteries from the standpoint of specific characteristics in long-term operation, are tens of times inferior to mass-produced heat engines. However, the basis for the use of chemical storage batteries as energy sources for electric cars in large cities is the fact that because of the capacity of storage batteries for fast recharges, an electric source can be used whose power is 4-5 times smaller than the power produced by heat engines. A number of American experts hold that despite their high cost, silver-zinc storage battereis can find applications in mass-produced machines: their cost is due to the high content of silver (up to 30% by weight), but 99% of the silver can be recovered and used again. Special nickel-zinc storage batteries usually employed in radio electronics possess high specific characteristics, but are expensive. At the present time, automobile transportation can actually count on the heaviest, but at the same time the cheapest, lead and iron-nickel batteries. Depending on their mineral resources different countries will prefer the former or the latter. Thus, in Great Britain, which operates more than one-half of the existing electric cars, lead batteries are chiefly employed.

In the Soviet Union, the traction systems used are mainly iron-nickel storage batteries.

Among the new storage batteries, the most promising is for use in traction are nickel-zinc and air-zinc types. The latter have characteristics that are equal to those of silver-zinc batteries, but they should be only twice as expensive as lead batteries in mass production. According to literature data, air-zinc batteries are being developed in the U.S.A. and England.

In 1966, reports appeared in the literature on fundamentally new types of storage batteries being developed in the U.S.A: sodium-sulfur and lithium-chlorine types. In these batteries, the electrodes are in the molten state, and the electrolyte is a solid ion-conducting oxide matrix. Sodium-sulphur and lithium-chlorine storage batteries are operated at working temperatures of several hundred degrees (500-600°C.). The specific power and specific energy are as high as 70-80 W/kg and 300-400 W hr/kg, which is sufficient to run a medium-class electric car without recharging over distances of 150-200 km under urban conditions. The specific characteristics of molten electrochemical systems allow forced charging rates.

In practice, such storage batteries can be charged up in a few minutes.

The companies Ford and Chrysler, which have developed the sodium-sulphur and lithium-chlorine storage batteries, propose to market experimental electric cars with such batteries in 1970-71.

Electric cars powered by storage batteries do not contaminate atmospheric air.

Fuel cells. Perfectly pure water is a poor conductor of electric current. However, it can be changed into an adequate conductor by dissolving a small amount of inorganic acids or salts. Why is this so?

Let us assume that sulfuric acid (H_2SO_4) is dissolved in water. When it comes in contact with water the electrically neutral sulfuric acid molecule breaks up into three ions: two positively charge hydrogen ions (H^+) and one sulfate ion bearing a double negative charge (SO_4^{--}).

This process, called dissociation, is represented by the formula

$$H_2SO_4 \rightarrow 2H^+ + SO_4^{--}.$$

If a voltage is applied to the electrodes, the positively charged ions will migrate toward the cathode, and the negative ones toward the anode (Fig. 54). The solution will thus conduct an electric current.

When the sulfate ion reaches the anode, it will give up to the latter its two "excess" electrons, forming an electrically neutral group of atoms SO_4, which will immediately react with water to yield sulfuric acid and oxygen

$$2SO_4 + 2H_2O \rightarrow 2H_2SO_4 + O_2.$$

Oxygen will be evolved in the gaseous form at the anode, and the sulfuric acid molecule will again dissociate into ions.

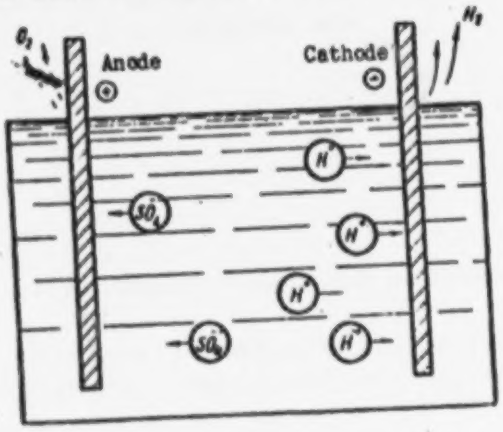

Fig. 54. Diagram of electrolysis.

As they approach the cathode, the hydrogen ions acquire the excess electrons located in this region, are neutralized, and the gaseous hydrogen thus produced will begin to be evolved at the cathode.

The mechanism of this process is called electrolysis. Its end result is the decomposition of the solvent (water) into hydrogen and oxygen. Electrical energy is required to drive this process.

If the reverse process is carried out, i.e., electrodes are immersed into a sulfuric acid solution and oxygen is supplied to the anode and hydrogen to the cathode, water will be formed from the oxygen and hydrogen molecules, and the process itself will be associated with the generation of electric current in the external circuit.

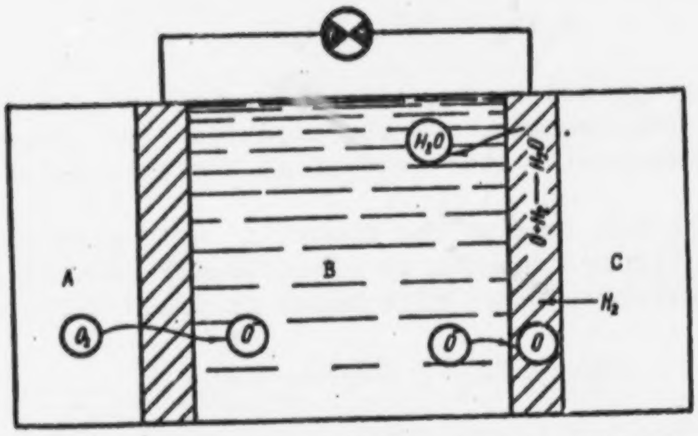

Fig. 55. Diagram of the simplest hydrogen-oxygen fuel cell: A - oxygen under pressure; B - electrolyte; C - hydrogen under pressure.

A diagram of such a model of hydrogen-oxygen cell is shown in Fig. 55.

Hydrogen and oxygen are supplied under pressure to porous platinum electrodes. On passing through the electrode, the oxygen molecules capture electrons from the surface of the pores in the metal, change into negatively charged ions, enter the electrolyte, and move to the other electrode. Here they give up their electrons and combine with hydrogen molecules, forming water. This reaction, which takes place in the pores of the electrode, is associated with the evolution of energy, which is expended on the generation of a flow of electrons, i.e., of an electric current.

The above-described device is called a fuel cell. It operates silently with an efficiency close to 100%. Its working temperature is 150-200°C. The electrode material used may be platinum, nickel and other metals, and the electrolytes may be solutions of sulfuric acid, potassium hydroxide etc. The gases used do not have to be hydrogen and oxygen. The characteristics of modern prospective fuel cells are listed in Table 13.

Table 13

Type of Element		Specific Characteristics in 1966, kg/kW		Specific Characteristics expected in 1970, kg/kW	Specific Characteristics expected in 1975, kg/kW
Fuel	Oxidizer	In Long-term Operation	At Peak Performance		
Hydrogen	Oxygen	20—25	10—15	8—10	4—5
	Air	25—35	13—18	10—12	5—6
Hydrazine	Oxygen	20—35	10—12	7—9	4—5
	Air	25—35	12—15	9—10	5—6
Methanol	Oxygen	50—60	30	30	18—20
	Air	70—80	35—40	32—35	20—25
Propane	Oxygen	80—100	—	—	—
	Air	100—120	—	—	—

To date, the hydrogen-oxygen fuel cells have been the ones most thoroughly developed. Their adoption in transportation is hindered mainly by their high cost due to the use of high purity hydrogen and precious metals in the electrode catalyst.

Of great interest for the development of tractive fuel cells is the cracking of hydrocarbon fuels (for example, methanol) and the cracking of ammonia, which are processes resulting in the formation of hydrogen. The optimum oxidizer is atmospheric oxygen. In the U.S.A. , England and France, nonprecious catalysts such as oxides and other compounds of certain metals are used to accelerate the process.

Another promising trend in the development of fuel cells for transportation is aimed at perfecting a cell with a liquid fuel, chiefly hydrazine and methanol.

The direct oxidation of kerosene, gasoline, and diesel fuel is still in the stage of laboratory testing.

Considering the insufficiently high specific characteristics of modern chemical energy sources of define interest at the present time is the combined utilization of low power internal combustion engines and chemical storage batteries. These energy sources operate under buffer conditions, with the storage battery serving as the source of traction and the heat engine constantly charging it. This combined power plant (CPP), under development at LANE, permits a sharp reduction in the emission of toxic components into the atmosphere.

There are also other systems.

Atomic engines. At the present time, nuclear energy is liberated by the fission of nuclei (in atomic bombs and power plants), by the fusion of nuclei (in hydrogen bombs) or as a result of the radioactivity of certain substances.

In the next 20-30 years, the fusion of nuclei will scarcely become a controlled thermonuclear reaction, and it is premature to discuss the prospects of automotive atomic engines operating on this principle.

To achieve the reaction of nuclear fission, to start the reaction and keep it going, a large critical mass is required, and the reactor itself must have a reliable shield weighing several tons. The use of the nuclear fission reaction becomes warranted only in the production of power tens and hundreds of times greater than the amounts required today for generating the motive power of an automobile.

Table 14

Type	Power, W	Service life, months	Radioactive Substance Used
SNAP 1A	125,0	12	Cesium 144
SNAP 7D	60,0	12	Strontium 90
SNAP 13	12,5	4	Curium 242

It would be premature at the present time to discuss the prospects for the use in automobiles of devices operating on the energy evolved by the radioactivity of certain elements. Thus far, they have been applied only in thermoelectric semiconductor converters with germanium or silicon cells having efficiencies of 0.1-1.0%, and also in thermionic converters with efficiencies of 15-20%. The power of these batteries is very low and as a rule does not exceed 500 W. As an example, Table 14 lists the main parameters of SNAP type thermobatteries produced by the American company Martin Marietta.

Table 15

Converter	Working Temperature °C.	Thermal Efficiency	Overall Efficiency	Specific Power, hp/kg
Carburetor engine (degree of compression $\varepsilon = 8.5$)	—	0,57	0,30	1,0
Thermoelectric Converter	1200	0,21	—	0,2
	850	0,17	0,04—0,05	0,03
	300	0,08	0,04—0,05	0,03
Thermionic converter	1800	0,35	0,15	(0,65)
	1150	0,15	—	(0,65)
Fuel cell	—	(1,0)	0,6—0,7	0,18

Note. Thermal efficiency - ratio of converted heat energy to input energy; overall efficiency - ratio of shaft energy to input energy. The overall efficiency takes into account all the losses, and the thermal efficiency, only the cycle losses.

The data given in parentheses are tentative.

The value of the specific power of a thermoelectric converter, equal to 0.2 hp/kg, corresponds to the specific power of a single cell, equal to 0.03 hp/kg - the specific power of the entire assembled converter.

To conclude the chapter, we present comparative Table 15 of mechanical and nonmechanical energy conversion devices, which permits an evaluation of the present efficiency of some of the devices described. Table 15 was taken from materials of official U.S. publications.

Table 16 lists the sanitary norms for the contents of toxic substances in the atmosphere and Table 17, their concentration indices.

Table 16

Sanitary Norms of Maximum Content of Toxic Substances in Atmospheric Air

Component	Chemical Formula	Maximum Permissible Concentrations in the Atmosphere of Populated Areas						Maximum Permissible Concentrations at Work Stations			Maximum Permissible Concentrations in Mine Atmosphere		
		Mean Daily			Highest Single								
		mg/l	% By Volume	ppm (parts per million)	mg/l	% By Volume	ppm (parts per million)	mg/l	% By Volume	ppm (parts per million)	mg/l	% By Volume	ppm (parts per million)
Acrolein Formaldehyde	CH_2CHCHO $HCHO$	10.10^{-5} $1,2.10^{-5}$	$4,4.10^{-6}$ 1.10^{-6}	0,044 0,01	30.10^{-5} $3,5.10^{-5}$	13.10^{-6} $2,9.10^{-6}$	0,13 0,029	$0,7.10^{-3}$ 1.10^{-3}	3.10^{-5} $8,15.10^{-5}$	0,3 0,815	$0,7.10^{-3}$ 1.10^{-3}	3.10^{-5} $8,15.10^{-5}$	0,3 0,815
Carbon Dioxide	CO_2	Not specified									For mine shafts 9,0	0,5	5000
Carbon Monoxide	CO	100.10^{-5}	$87,3.10^{-6}$	0,873	600.10^{-5}	520.10^{-6}	5,2	20.10^{-3}	175.10^{-3}	17,5	20.10^{-3}	175.10^{-5}	17,5
Sulfur Dioxide	SO_2	15.10^{-5}	$5,7.10^{-6}$	0,057	50.10^{-5}	19.10^{-6}	0,19	10.10^{-3}	$38,2.10^{-5}$	3,82	10.10^{-3}	$38,2.10^{-5}$	3,82
Hydrocarbons (total)	C_nH_m	For Gasoline 150.10^{-5}			500.10^{-5}			For Gasoline 100.10^{-3}			For Methane 4,8	0,75	7500
Nitrogen Oxide (total	N_xO_y	In terms of nitrogen pentoxide N_2O_5 10.10^{-5}	$2,3.10^{-6}$	0,023	30.10^{-5}	$6,8.10^{-6}$	0,068	5.10^{-3}	$7,32.10^{-5}$	7,32	In terms of NO_2 1.10^{-3}	20.10^{-5}	2,0
Soot	C	For coal dust containing no free SiO_2 5.10^{-5}	—	—	15.10^{-5}	—	—	10.10^{-3}	—	—	10.10^{-3}	—	—
Benz(o)pyrene*	$C_{20}H_{12}$	Emission standards being established											

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* The content of benz(o)pyrene is usually given in γ/m^3, γ being one millionth of a gram.

Table 17

Concentration Indices of Toxic Components of Exhaust Gases.

Toxic Component	1% by Volume		1 mg/1		1 ppm (parts per million)	
	mg/1	ppm (parts per million)	% By Volume	ppm (parts per million)	% By Volume	mg/1
Carbon monoxide	11,45	10000	0,0873	873	0,0001	0,001145
Acrolein	22,50	10000	0,0445	445	0,0001	0,00225
Formaldehyde	12,30	10000	0,0815	815	0,0001	0,001230
Sulfur dioxide	26,60	10000	0,0376	376	0,0001	0,00266
Hydrocarbons (total) in terms of hexane	35,2	10000	0,0285	285	0,0001	0,00352
Nitrogen oxides (in terms of nitrogen pentoxide)	44,1	100000	0,0227	227	0,0001	0,00141

AFTERWORD

Academician B. S. Stechkin

Hero of Socialist Labor, recipient of the Lenin Prize, and member of the Scientific Council
on the Problem of Protection of the Air Reservoir from Pollution by Noxious Substances,
of the State Committee on Science and Technology of the Council of Ministers of the USSR.

The crowding of automobiles in urban areas makes it necessary, in addition to creating favorable conditions for the flow of traffic with a minimum loss of time, to provide parking spaces, develop a system of service and filling stations, and solve the problems of pollution of air by the toxic substances of exhaust gases and traffic noise in cities and suburbs. These problems should be solved as part of urban planning problems as well as in meeting the requirements of urban transportation.

The problem of decreasing the toxic exhausts of automobiles has been particularly pressing in the last few years.

According to published data, in 1962, automobiles in the U.S.A. discharged 90 million tons of carbon monoxide, 12 million tons of hydrocarbons, 4.5-13.5 million tons of nitrogen oxides and hundreds of thousands of tons of aldehydes, sulfur compounds, organic acids, soot, and lead compounds into the atmosphere.

A survey of European cities for 1960-65 showed that the average carbon monoxide concentration in Paris was 45.6 mg/m^3, in Marseilles 68.98 mg/m^3, in Zurich and Basel, 40 mg/m^3. Comparing the above data with the average maximum permissible concentration of carbon monoxide, 1 mg/m^3 of air, one can see how serious the problem of control of toxic automobile exhausts really is. In some cities of the Soviet Union, the content of toxic components of automobile exhausts in air is lower than in U.S. and European cities, but it also exceeds the permissible norm.

One of the methods used to reduce the emission of carbon monoxide and hydrocarbons from an engine has been to lean out the air-gasoline mixture. Numerous studies have shown that when the mixture is leaned out to an excess air coefficient $\alpha = 1.05\text{-}1.15$, the emission of carbon monoxide decreases to a few tenths of one percent, instead of the 5-10% in power adjustments.

The road leading to the solution of the problem of cleaning up internal combustion engines appeared to be clear. However, studies carried out in the last few years at LANE under the direction of Prof. I. L. Varshavskiy showed that precisely at these excess air coefficients, the formation of nitrogen oxides and their emission into the atmosphere increases by almost a factor of 10. Since the maximum permissible concentration of nitrogen oxides in the atmosphere of cities is ten times less than that of carbon monoxide, the problem of reducing the total toxicity of the exhaust gases of automobile engines cannot be solved by the above-indicated leaning-out limits.

As pointed out in this book, according to Varshavskiy's recommendations, the usual engine power adjustments should be made corresponding to the minimum emissions of nitrogen oxides, and large amounts of the emitted carbon monoxide and hydrocarbons should be subjected to flameless afterburning in catalytic neutralizers, or overleaning of the mixture should be achieved by special methods (laminar distribution of the mixture in the cylinder, intensified electric ignition, prechamber-flame ignition) down to a limit where the total specific toxicity will be minimal, and the power decrease will be offset by supercharging. He also recommends other methods such as water injection.

The future will show which methods will prove the most constructive, reliable, and economical.

The last few years have seen an emphasis on the problem of replacement of automobiles with internal combustion piston engines by electric cars with electrochemical energy sources that facilitate the control of air pollution and noise.

The technical and economic indices of electric cars depend primarily on the properties of their electrochemical energy sources - storage batteries or fuel cells. Today, however, the weight per kilowatt of power (for a five-hour operation) for lead, iron-nickel and nickel-cadmium storage batteries is approximately 250 kg/kW, for silver-zinc and for air-zinc storage batteries being developed, 35-55 kg/kW, and for fuel cells: operating on oxygen and hydrogen, 20-25 kg/kW, on air and hydrogen, 30-35 kg/kW, and on methanol and air, 70-80 kg/kW.

Modern carburetor automobile engines have a weight of 2-3 kg/kW, and diesels, 3-7 kg/kW. We can see that the main index of a transport engine in terms of modern electrochemical energy sources is one or two orders of magnitude less than that of an internal combustion engine.

In addition, fuel cells have not yet been perfected to the point where they can be used in industry.

The above factors combined with other causes will postpone the replacement of automobiles by electric cars for many years. Thus, research aimed at decreasing the emission of toxic components by automobiles and internal combustion engines into the atmosphere of cities and industrial centers is very timely and pressing. Since the cost and weight factors of chemical sources of energy do not permit the conversion of most automobiles to electric traction in the next 10-15 years, it is desirable, in addition to studying ways of decreasing the toxicity of automobile exhausts, to expand the research being currently conducted under the direction of Prof. I. L. Varshavskiy, aimed at the creation of a combined power plant (CPP), which I have advocated for several years now, involving the combined use of a low power internal combustion engine operating under steady conditions and a buffer storage battery.

When traction electric motors require a greater power than that supplied by the internal combustion engine, the buffer storage battery operates in parallel with the internal combustion engine, and when the energy expended by the heat engines decreases (coasting, parking or stopping at a traffic light), the storage battery is charged. It is important to note that an internal combustion engine operating constantly under steady conditions can be specially constructed. Recent progress in high speed engines makes it possible to construct the motors for the CPP system with a required power of 6-12 kW, rotational speed of the crankshaft of 8000-10,000 rpm at a very low average piston speed, and with complete utilization of the effects of air vibration at the intake and exhaust. The high rotational speed of the engine crankshaft makes it possible to increase the compression ratio without risking the appearance of knocking and, with intensified ignition, to achieve a stable operation of the engine at $\alpha \geqslant 1.35$ under steady conditions, resulting in the absence of carbon monoxide and minimum amounts of nitrogen oxides. A one-liter capacity at high rotational speeds will be sufficient despite the high value of the excess air coefficient α .

In the future, the system with a CPP can also be used when the heat engine is replaced by a fuel cell.

One of the necessary elements of a CPP is a system controlling the internal combustion engine, which should be turned on or off depending on the degree of charge of the buffer storage battery and the power required by the traction electric motor.

Theoretical and structural studies of power plants for various types of passenger automobiles carried out at LANE have shown that if one considers a passenger car weighing 0.[illegible] ton with a driving range of 60 km, the total weight of the internal combustion engine, generator, buffer battery, traction electric motor, control system and fuel system with stored fuel will be 78.5 kg, which is 13.1% of the total weight of the automobile, and in the case of a light taxicab weighing 2 tons and having a daily range of 250 km, the total weight of the above units and systems will be 242 kg, i.e., 12.1% of the total weight of the taxicab.

Comparison of data on an automobile with an internal combustion engine and an electric car with a CPP shows that the latter vehicle has fully acceptable characteristics and may be regarded as one of the possible variants for replacing the automobile in cities.

No books have thus far been published in the USSR on the problem of control of the toxicity of automobile exhausts and internal combustion engines. Individual articles in periodicals have appeared only in the last few years, and in 1966, a collection printed in a small edition was published containing reports of Soviet scientists at a Moscow symposium (with the participation of experts from member countries by the Council of Mutual Assistance) of the Scientific Council on the Problem of "Protection of the Air Reservoir from Pollution with Noxious Substances" of the State Committee on Science and Technology of the Council of Ministers of the USSR. For a major nationwide social problem such as the protection of the air reservoir this is obviously not enough. I, therefore, give herewith my unqualified support to the publication by the "Transport" Press of the book "How to Neutralize Automobile Exhaust Gases" by Doctor of Technical Sciences Prof. I. L. Varshavskiy, Honored Scientist and Engineer of the RSFSR, and Candidate of Technical Sciences R. V. Malov.

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DETERMINATION OF THE COMPOSITION OF EXHAUST GASES FOR CARBURETOR ENGINES UNDER DIFFERENT OPERATING CONDITIONS

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From Scientific Research Institute of Information for the Automobile Industry (NIINAVTOPROM). Reference Department, Moscow, p. 3-23, (1966).

In connection with the increased use of internal combustion engines in industry, engineers steadily encounter problems whose solutions become more complex with each passing year. The consumption and pollution of air are a phenomenon accompanying the combustion process. The level of air pollution because of automobile exhaust gases already has become the chief problem of the day, since a heavy air pollution has a deleterious effect on man, animals and the plant world.

Given below is a report on some basic problems of exhaust gases (as sources of air pollution).

The world consumption of energy [1] has been steadily rising in the last two decades (along a nearly straight line, Fig. 1). At the present time, it is equivalent to 4.5 billion tons in standard coal units (SCU) per year (7000 kcal/kg). The energy obtained from crude oil and natural gas has long surpassed the energy obtained from coal.

Steeper curves illustrate the growth in the volume of motor transport. The increase in automobiles in the German Federal Republic (12.5 million automobiles; yearly increase, 6.5%) considerably exceeds the increase in the U. S. A. (93 million automobiles; increase 3.7%), since Europe is still at an early stage of motorization. Recently, an article written by a scientist has appeared in the world press stating that in the next century, automobiles will exhaust the supply of air on our planet. It is probable that 100 years hence, there will again be held a congress of FISITA at which the engineers will be dealing with urgent problems connected with automobiles that will not be running on gasoline. According to the author's calculations, the supply of air will suffice for another 117,000 years (for a combustion of 4.5 billion tons of SCU per year). Considering the increase in automobiles, one can determine to what extent the undesirable emission products of internal combustion engines should be reduced in order to preserve the present level of air purity. For example, in the course of the next decade, the noxious impurities of automobile exhaust gases in the German Federal Republic (GFR) will have to be cut by 40% while preserving the current level of production.

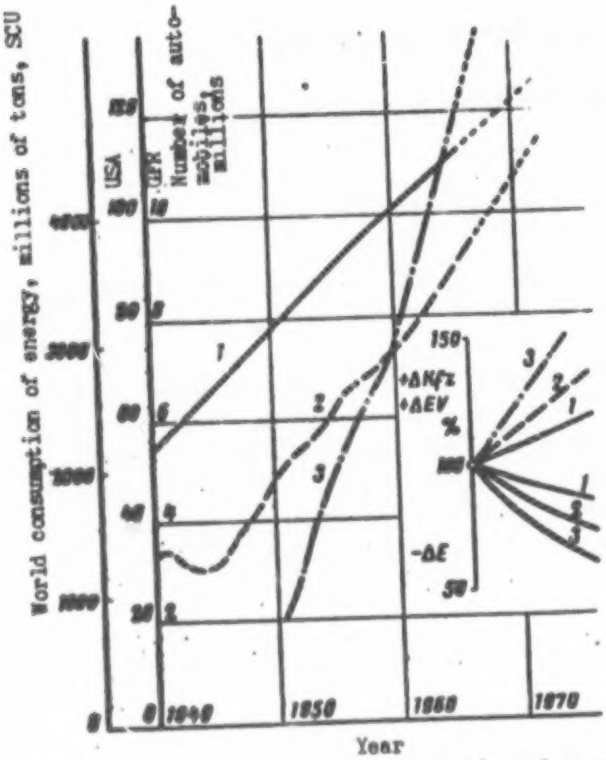


Fig. 1. Growth of the world consumption of energy and number of automobiles; right - required reduction of emission products ΔE to keep the air pollution level unchanged in the course of 10 years:

1 - world consumption of energy; 2 - number of automobiles in the USA; 3 - number of automobiles in the GFR:

+Δ Kfz - volume of motor transport
+Δ EV - world consumption of energy

Effect of the Operation of a Motor on the Emission of CO, CH, and NO with Exhaust Gases

The most harmful component in the exhaust gases of a carburetor engine is carbon monoxide CO, since it is very toxic. CO is the product of combustion of carbon, which is contained in gasoline and in atmospheric oxygen, and theoretically, in the presence of excess air $\lambda>1$, carbon monoxide should be neutralized (Fig. 2).

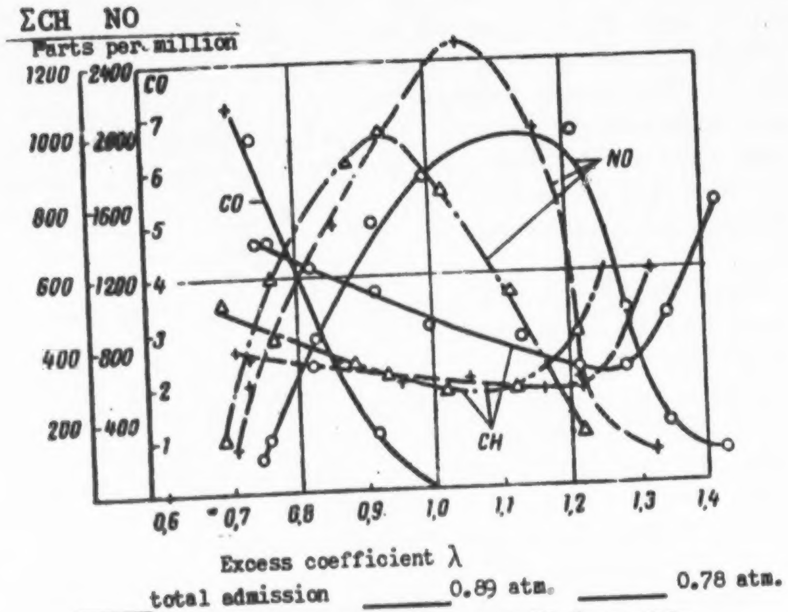


Fig. 2. Exhaust gas components CO, CH, NO for a one-cylinder four-stroke carburetor engine; number of revolutions n = 1800 rpm.

Instead of CO, harmless carbon dioxide CO_2 is formed. The CO_2 remains harmless until it completely displaces the oxygen of air. Unfortunately, an engine operating on gasoline with a 10-20% deficiency of air develops the maximum average pressure as a result of a high combustion rate, with the formation of 3.5-7.0% of CO (by volume). The CO content of the exhaust gas, which is almost independent of the design of the engine, fuel or type of carburetion, depends on the composition of the mixture and also on the degree of admission. The CO content in the exhaust gases of the engine is 1000 times greater than in air with a CO content that man can still tolerate for 8 hr. The so-called MAC (maximum concentration of noxious gases at a work station) is 0.01% = 100 cm^3/m^3 CO. Thus it is necessary to point out a steady and heavy pollution of air with the exhaust gases. The maximum content of CO, 30 cm^3/m^3, has been recorded in the streets of Paris and London.

This situation now exists in many places, but we should not lose heart, because:

an increase in the maximum quantity of CO will not take place in the future, since highways are designed for a given number of automobiles;

according to medical data [5], chronic poisoning with carbon monoxide is not dangerous, since when fresh air is supplied, the headache goes away and the sluggishness disappears, both of these symptoms being manifestations of light poisoning with this gas.

The problem of air hygiene in Europe has first priority. Of major interest is the driver himself, who is subjected to the action of CO more than anyone [6]. The carbon monoxide content of the driver's blood hemoglobin may rise to 4.5% CO-Hb, whereas in the blood hemoglobin of a traffic controller after 5 hr of work, the carbon monoxide content is only 1.6% CO-Hb (nonsmoking traffic controller). In the case of a smoking traffic controller, however, at the end of the working day, the CO content of the hemoglobin is 3.65% CO-Hb. The permissible carbon content of hemoglobin is 15% CO-Hb.

A major importance is attributed to unburned hydrocarbons CH in the exhaust gases in Los Angeles, California, after it was demonstrated that as a result of photochemical reactions in sunlight under certain meteorological conditions, hydrocarbons promote the formation of smog. The unburned hydrocarbons are given in ppm (parts per million), i. e., in cm^3/m^3, and are referred to hexane C_6H_{14}. Their content in the exhaust gas is explained by effects of cooling of the combustion chamber walls. The minimum CH values are reached at $\lambda = 1.2$-1.3; a sharp increase in a lean mixture with $\lambda = 1.3$ is explained by a slow combustion and missing of the engine. CH emissions depend on the form of the combustion chamber, with a definite role being played by the ratio of surface to volume.

At this point one must also mention the fact that a modern automobile carburetor engine with an excess air $\lambda = 1.05$-1.15 is characterized by a minimum fuel consumption.

Less closely studied are nitrogen oxides N_xO_y, which as a result of oxidation of atmospheric nitrogen are formed in the engine at a high temperature. The maximum concentrations are observed at $\lambda \approx 1.0$.

Nitric oxide NO is very toxic; its MAC is only 25 cm^3/m^3, but in large cities of the GFR, values no higher than 0.4 cm^3/m^3 have been reported [7], which can hardly be accounted for solely in terms of automobile exhaust. In Los Angeles, a maximum of 0.3 cm^3/m^3 is already being used in the calculations. The nitric oxide content of exhaust gases has not yet been determined.

Results of bench tests were used to compile graphs of average pressure which clearly show lines of constant value of CO% - CH cm^3/m^3 (Fig. 3).

All the measured quantities are valid only for one cylinder of multicylinder engines. The crosshatched portion of the graph shows that the value of the exhaust established in California has increased. As a rule, different cylinders have different values, so that the percentage value of the total emission of combustion products is considered to be the average. The latter is determined by considering the type of carburetion [8], ripple in the intake manifold [9] and type of mixture in the intake system. In normal operation, the composition of the mixture supplied to the individual cylinders is entirely different than during acceleration or braking, since, as a result of a partial condensation in the intake manifold, this always leads to the formation of extra fuel. This applies primarily to carburetor engines.

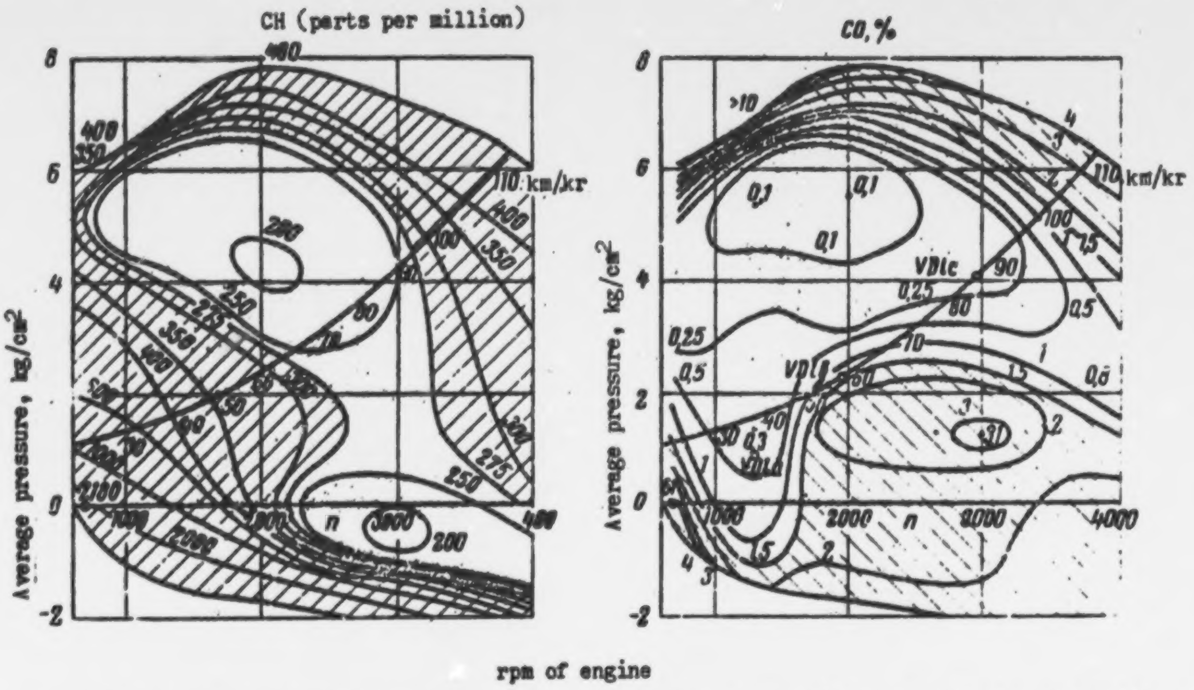


Fig. 3. Graphs of CH and CO for the fourth cylinder of a four-cylinder four-stroke carburetor engine.

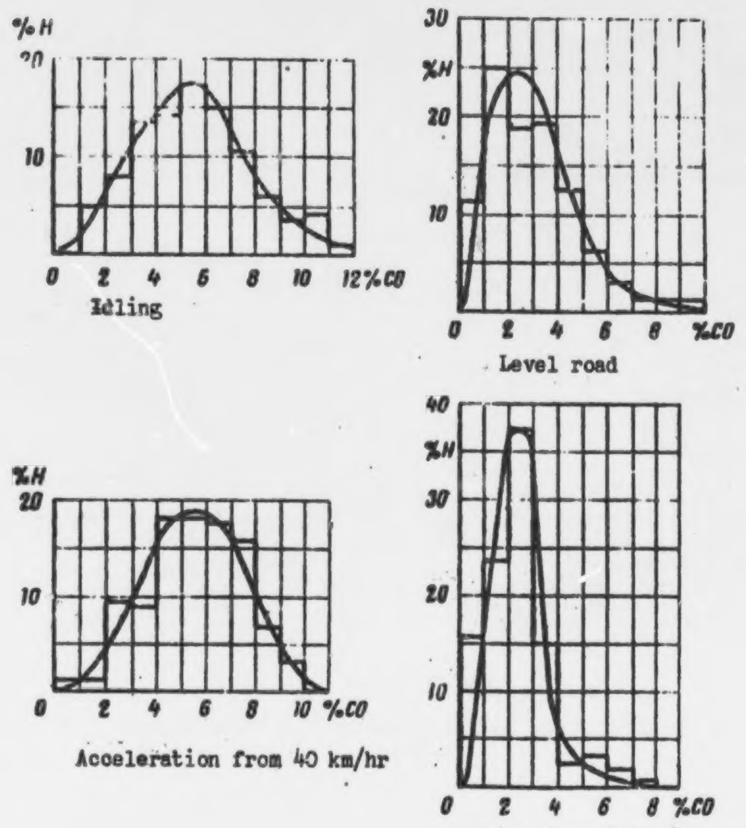
Even the same automobiles under the same operating conditions show different contents of CO in the exhaust gases. This was revealed by an analysis of the composition of the exhaust gases of 80 medium cars [10]. The analysis showed the values of CO to be distributed in the range of 1-12% (Fig. 4).

The composition of the exhaust gases of individual automobile engines varies with the design of the engine, its size, adjustment, and maintenance. In order to approach the problem of the quantity of noxious components of exhaust gases, it is necessary to proceed from the "pattern of movement" characteristic of the traffic flow. Such a "pattern of movement" is currently being studied on passenger cars in large German cities [7].

Amount of Exhaust Gases Associated with Speed Shifting

The amount of exhaust gases associated with simple speed shifting for a given automobile is clearly illustrated in the graph (Fig. 5). The fuel consumption in 1/100 km at an average traveling speed is also shown.

The following relationship exists between the fuel consumption B, air



Idling

Level road

Acceleration from 40 km/hr

Braking from 60 km/hr.

Fig. 4. Curves of CO distribution in exhaust gases of 80 cars with a displacement of 1.2-1.5 l under different operating conditions.

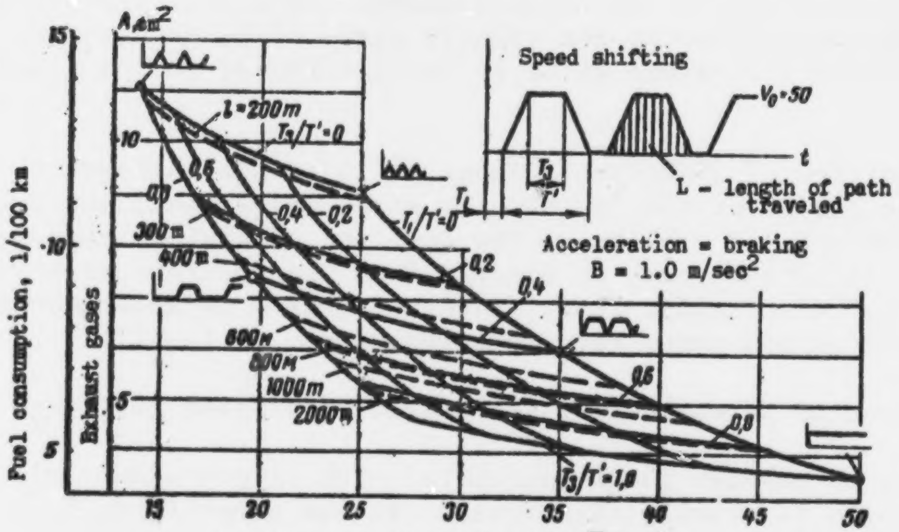


Fig. 5. Fuel consumption and exhaust gases during shifting of speeds 0-50-0-50-0 km/hr.

consumption L and the quantity of exhaust gas A (dry) at = 1.0:
9339 x B (l/hr) = L x (l/hr); 0.94 x L = (l/hr) = A (l/hr)/

Neither the percent volume nor the amount of CO and CH emitted per unit time constitutes an index of air pollution. The ratio of the amount of exhaust gas to the path traveled in cm^3/m or l/km is a unit of measurement of air pollution. This dimension (cm^3/m or l/km) is the average amount of gas discharged by the automobile into the atmosphere. It is also used for the exhaust components CO, CH, etc. Changes in the velocity of the automobile as a function of time are:

engine idling when the automobile is stationary (time T_1);
acceleration in m/sec^2 (T_2);
uniform speed of 50 km/hr (T_3);
deceleration $B_v = B_b$ m/sec^2 (T_2);
time of run $T^1 = 2T_2+T_3$.

The variable T_1/T^1 (idling: time of run), T_3/T^1 (50 km/hr; time of run), and also the traveled path S are the parameters of the curves. The amount of exhaust gases, i. e., the air pollution, is minimum at a constant speed of 50 km/hr ($T_1/T^1 = 0$; $T_3/T^1 = 1.0$ (on the graph, 3.7 cm^2). Transport operating on liquid fuel at a maximum average speed causes least air pollution. The construction of roads and traffic control may aid considerably in obtaining clean air. The duration of idling ($T_1/T^1 = 0$) and also frequent stops considerably increase the amount of exhaust gases (on the graph, 11.6 cm^2).

California Tests

The test cycle in California consists of seven stages, each of which was carried out with different loads on the engine and different numbers of revolutions per minute (curves 0-13, Fig. 6).

The percent content of CO and CH in the exhaust gases was recorded at each stage. Calculation of the average content of CO and CH was carried out in units of weight, which take into account the duration of the stage and magnitude of the flows at each stage.

The permissible content of noxious components in accordance with recent determinations obtained from tests carried out in California amounts to the following: for engines with a displacement of 820-1640 cm^3, 2.3% CO and 410 cm^3/m^3 CH; for engines with a displacement of 1640-2290 cm^3, 2.0% CO and 350 cm^3/m^3 CH; for engines from 2290 cm^3 and up, 1.5% CO and 275 cm^3/m^3 CH.

As a result of gradation of the percent values, the quantity of exhaust gases of engines with different displacements was taken into account.

According to standards VDJ2282, the maximum amount of CO for 4.5% idling at a constant speed of 33-75% of the maximum speed, 2-4%, can no longer serve as the standard for air pollution. The total amount of CO can be determined if the fuel consumption and volume content of CO are known.

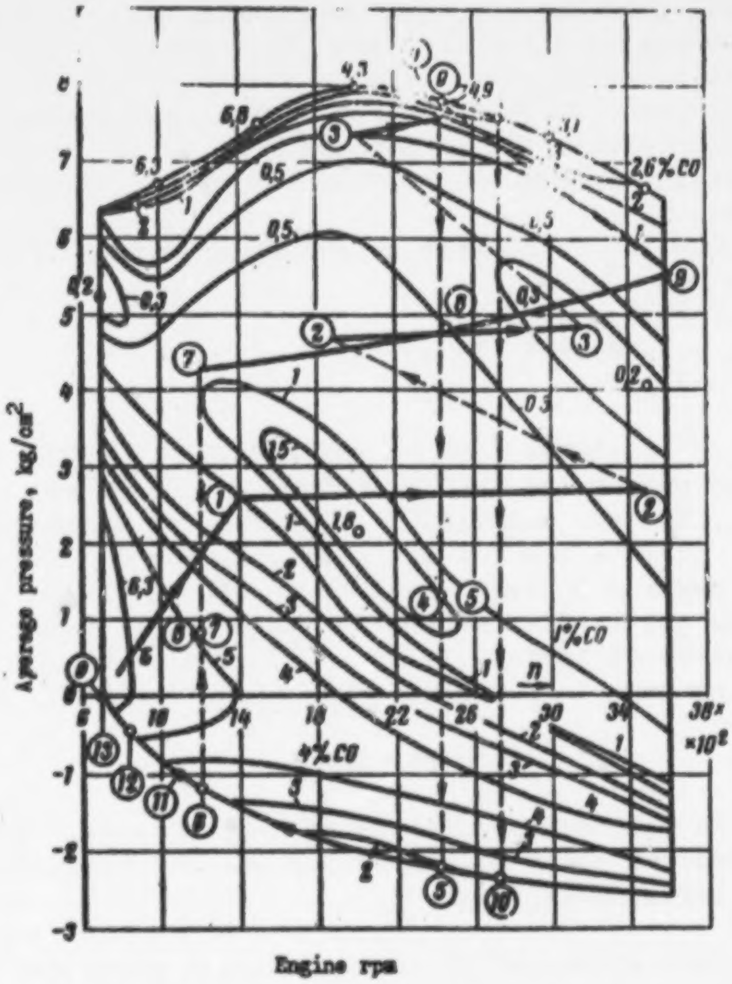


Fig. 6. Graph of operation of engine tested in California.

Thus, the maximum value is W = 0.783 (CO%) N. The individual stages of variable motion in the California tests are related to the average fuel consumption, in this case 0.2-2.0 cm^3/sec. The areas shown on the time diagram (Fig. 7) represent the fuel consumed and at the same time the amount of exhaust gases at the various stages. At each testing stage, the percent content of CO and CH is different. If one multiplies the amount of exhaust gas by the volume percent of CO and CH, one obtains the total amount of emitted gases in the form of the areas shown in Fig. 7.

From the above diagram it is evident that the largest amount corresponds to acceleration areas 2 and 6, the maximum discharge of unburned hydrocarbons being observed during the braking period 7. The content of noxious components during idling is considered insignificant.

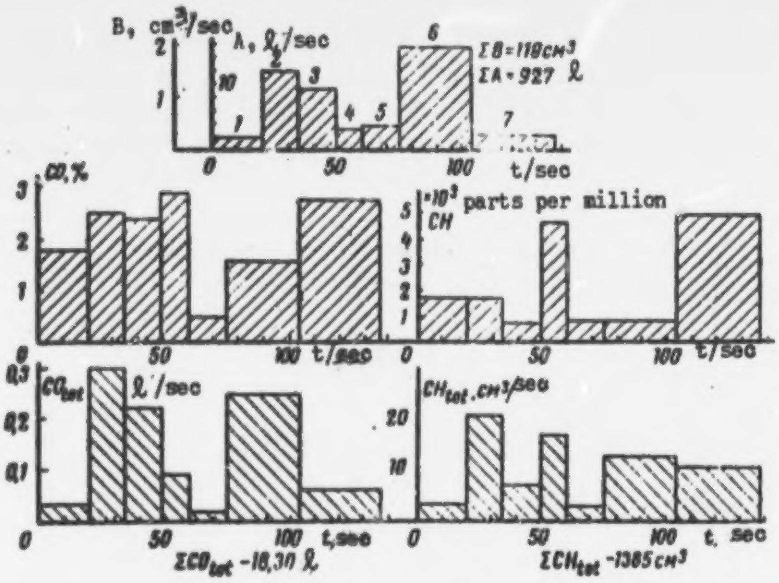


Fig. 7. Total amount of exhaust gases recorded during tests in California: 1 - idling; 2 - acceleration 0-48 km/hr; 3 - constant speed of 48 km/hr; 4 - braking, 48-24 km/hr; 5 - constant speed of 24 km/hr; 6 - acceleration, 24-80 km/hr; 7 - braking, 80-0 km/hr. B - amount of fuel; A - exhaust gases. For the exhaust gas with N - consumption standard (1/100 km) F (cm^2) = 0.783 N.

Content of CO and CH in the Engine Exhaust During Idling

A 5° opening of the butterfly valve has almost no effect on the idling speed, and a slight turn of the mixture control screw substantially increases the CO content of the exhaust gases (Fig. 8).

When the opening of the butterfly valve is 5°, 1/4 of a turn of the mixture control screw is enough to increase the percent content of CO from 0.5 to 6.3% in the exhaust gases. As is evident from the graph, during idling of the engine, the lean mixture contains the lowest percentage of CO.

At the maximum idling speed, the CO content of the exhaust gases is lowest. Such a state is best for the engine's operation.

The joint-stock company ŎAMTC, which deals with problems of pollution of air with gases, has presented a graph (Fig. 9) showing that the adjustment of the operation of an idling engine can be improved. By adjusting the carburetor on 4831 automobiles of 6 brands, CO was successfully reduced in the exhaust gases by approximately 3%. Comparison with general data leads to the conclusion that the CO content was reduced by 1/3.

Adjustment of idling also affects the partial load of the engine and the traction when the butterfly valve is closed. This was established as a result of seven tests conducted in California (Fig. 10). The idling operation of the engine was adjusted so that the CO content of the exhaust gases was 1.2-7.2%.

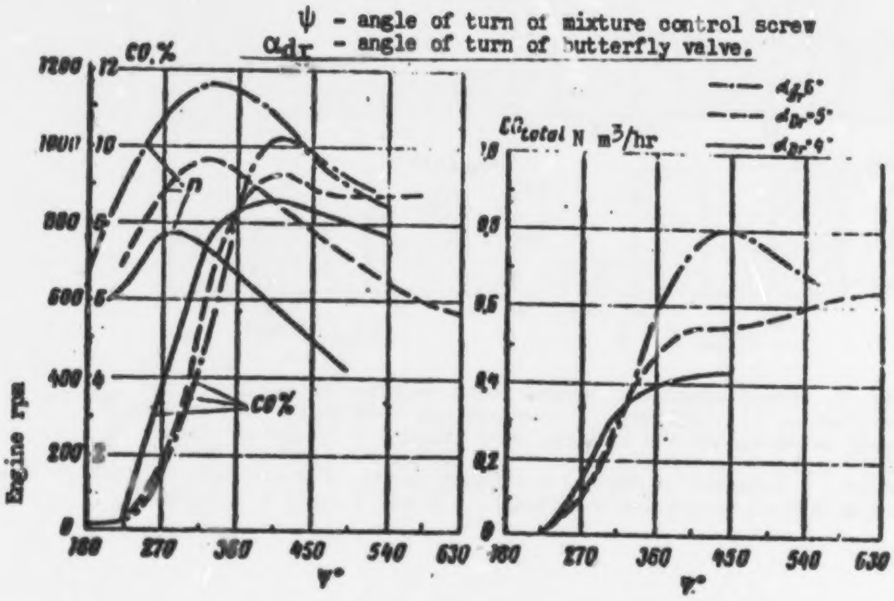


Fig. 8. CO content of exhaust gases during idling of engine.

The average CO content of exhaust gases established in tests allowing for the adjustment ranges from 1.6 to 4.5%.

If it is indeed possible to reduce the CO content during idling by 33%, as was done by ÖAMTC Co., the CO content of atmospheric air will decrease by a minimum of 20%. Therefore, such a solution to the problem is positive, since the adjustment of an idling engine by means of a measuring instrument is the only means of reducing the content of CO discharged by a carburetor engine into the atmosphere. Changing the fuel injection and an afterburner in the exhaust manifold will obviously be employed only several years from now.

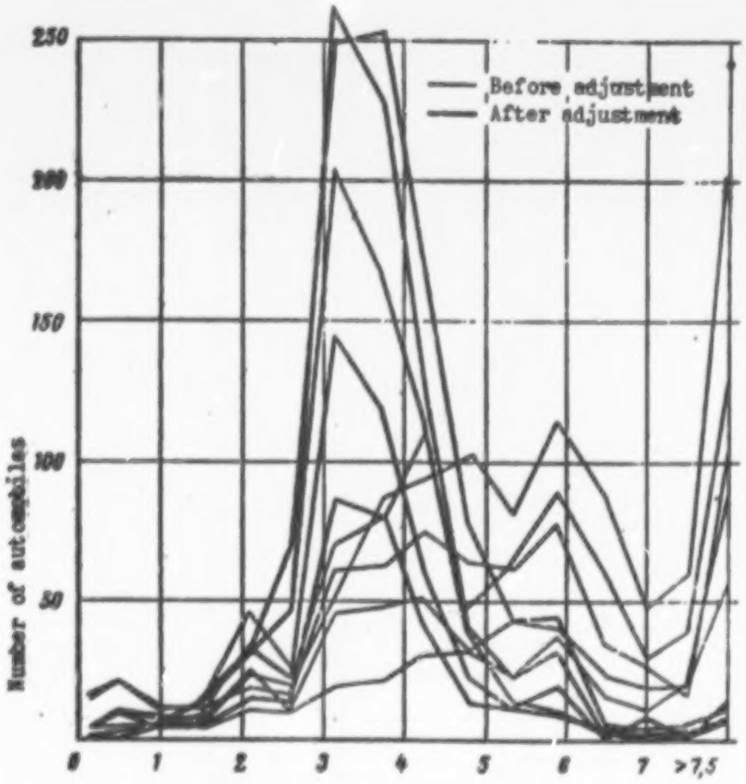


Fig. 9. Graph of CO content of exhaust gases during idling operation of engine, plotted by the joint-stock company ÖAMTC (Austria), taking into account the tests conducted in September 1965 on 4831 automobiles.

CO Content of Exhaust Gases Discharged into the Atmosphere

In the presence of excess air, practically no CO is detected in the exhaust gases of a carburetor engine . However, as the excess air increases, the average pressure decreases. This dependence is illustrated in the diagram (Fig. 11) in the form of areas.

The shapes of the curves of the working cycles, which alternate during stationary operation of the engine, are always different. The torque of numerous working cycles is measured on an engine test stand, no vibrations being recorded. Statistical treatment of a series of successive diagram p-V areas shows the recurrence period to be correct. The recurrent working cycles are never similar.

The maximum and minimum working areas are shown in the diagram of Fig. 12.

In the presence of the maximum excess of air ($\lambda = 1.51$), despite advanced ignition, there is a perceptible retarded combustion.

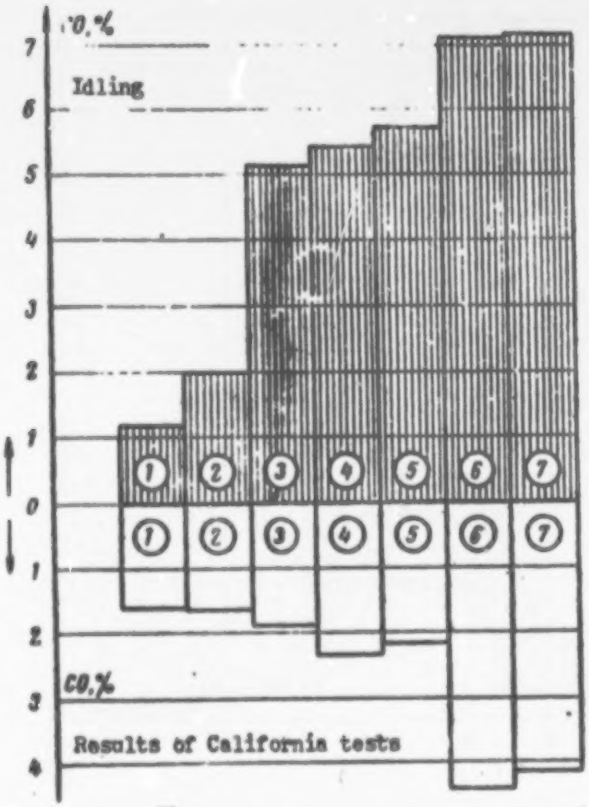


Fig. 10. Diagram of average CO content for different adjustments of idling engine and results of California tests conducted on an automobile with a 1.2 l displacement.

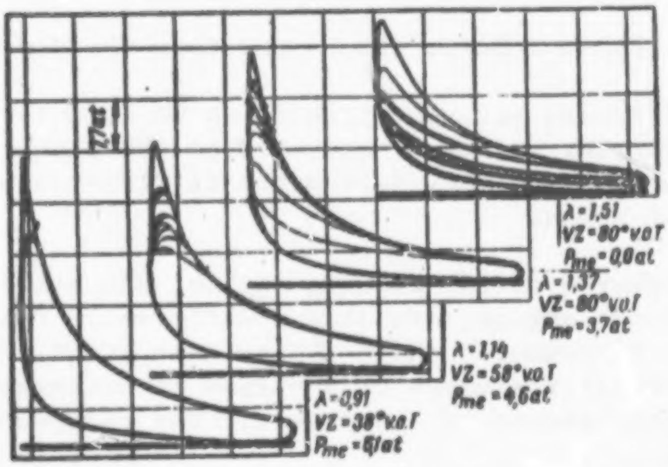


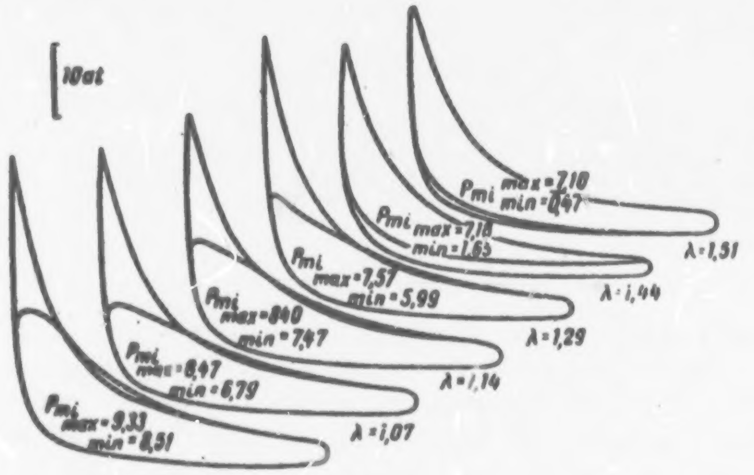
Fig. 11. Fluctuations of the indicator diagram (p-V) at different λ in stationary operation; VZ - ignition advance.

There are two causes of the fluctuation of the working areas:

irregularity in the supply of fuel to the combustion chamber during each working cycle;

the combustion process depends on the homogeneity of the combustible mixture.

Recording of the flame front with ion probes [4] showed that the local combustion rate varies considerably from one cycle to the next. The CO content of the exhaust gases also varies from one cycle to the next, and hence, its sum deviates from the theoretical value, which at $\lambda = 1$ should be equal to zero. Actually, however, a 1 to 2% CO content was recorded for this number $\lambda = 1$. This is explained by the frequency of the dependence and scatter of the λ values of the individual working cycles (which is not measured).



Excess coefficient = 0.91.

Fig. 12. Maximum fluctuations of the indicator diagram based on Fig. 11.

The recurrence frequency and height determine the average value of CO, since there are no "negative" values. In the presence of multicylinder engines with an inadequate distribution of the mixture, there are even more deviations from theory. The crosshatched surfaces of Fig. 13 should be regarded as the efficiencies of the engine relative to the production of CO.

The maximum power of a carburetor engine is reached in the presence of a 15% deficiency of air. The better one can differentiate between the scattering of the working cycles and the deviations of individual cylinders, the closer the optimum power comes to the proportional composition of the mixture corresponding to the excess air coefficient $\lambda = 1$. This is and continues to be the purpose of complete combustion.

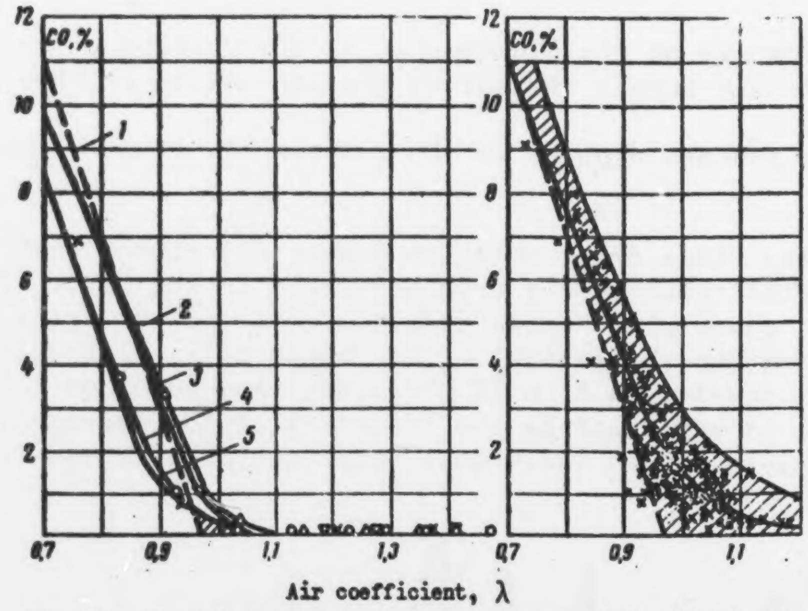


Fig. 13. CO content of exhaust gases of one-cylinder (left) and multicylinder (right) four-stroke carburetor engine:
1 - CO (theoretical); 2 - carburetor without correction for air consumption; 3 - carburetor with correction for air comsumption; 4 - injection into intake manifold; 5 - vaporizer.

Among the constructive possibilities of reducing the scattering of the working cycles, one must particularly emphasize the adjustment of fuel injection. The known advantage of adjusting the injection relative to the power and consumption before the carburetor amounts, on the one hand, to a slight throttling of the engine, and on the other hand, to an exact proportioning of the fuel mixture necessary for each cycle. The condensation of fuel in the intake pipe does not occur thanks to an adjustment of the injection. The amount of vapors which increases the CO content of exhaust gases becomes less if the nozzle is located near the valves. A static determination of the indicated mean pressure Pmi at a distance of 90 mm gave a considerably narrower band of scattering of the points than at a distance of 360 mm, particularly in the presence of the maximum excess of air (Fig. 14).

The next measure that can be used to reduce the scattering of the working cycles and hence the content of unburned products in the exhaust gases is the turbulence in the combustion chamber. The turbulence can be caused by the rotating generator in the intake pipe. More effective should be the counterturbulence, which arises during compression at a minimum volume of the combustion chamber.

Even a primitive rotating generator in the intake pipe can be used to reduce the scattering of maximum pressure for any proportional composition of the mixture.

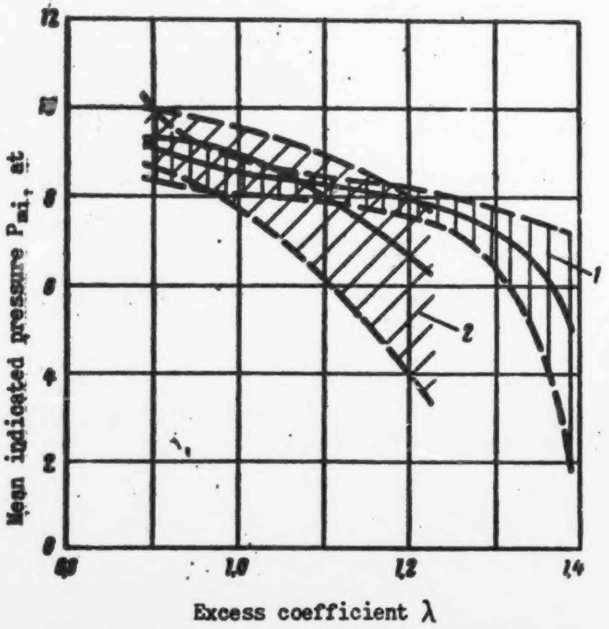


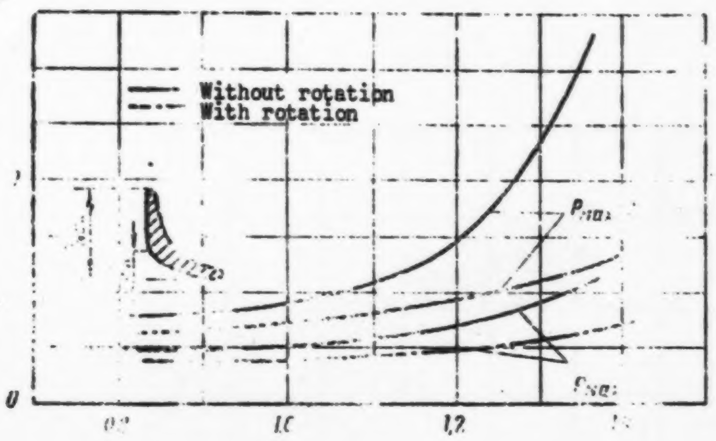
Fig. 14. Band of scattering of indicated mean pressure for nozzle located at 90 and 360 mm from t the intake valve as a function of the excess air coefficient λ:
1 - injection at a distance of 90 mm from the intake valve;
2 - injection at a distance of 360 mm from the intake valve.

If the coefficient of change $V = \frac{\text{mean pressure}}{\text{pressure scattering}} \times 100\%$ pertains to the thermal increase of pressure (maximum pressure minus the pressure at the end of the compression stroke), the difference is sufficiently obvious (Fig. 15).

The change of charge in the automobile engine is very difficult to control during changes of power, but this would undoubtedly lead to a reduction in the emission of noxious exhaust gases.

The problem facing engine specialists is to learn how to control the processes of carburetion and combustion of noxious impurities polluting the atmospheric air and to use an afterburning system which would neutralize the exhaust gases.

NOT REPRODUCIBLE



Excess coefficient λ

Fig. 15. Change V of maximum pressure P_{max}-Pk (P_k = pressure of compression as a function of λ).

Conclusion

The growing demand for energy in transportation calls for progress in the control of the purity of atmospheric air. The paper discusses the dependence between the noxious products of exhaust gases of automobile carburetor engines and the conditions of operation of the engines.

The maximum content of exhaust gases depends on the size of the engine and fuel consumption. An irregular combustion process in the individual cylinders and an inadequate distribution of the mixture in multicylinder engines also affect the emission products.

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